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Volume 105 1993

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A Journal of Scottish Natural History

THE SCOTTISH NATURALIST

Founded 1871

A Journal of Scottish Natural History

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NATURAL HISTORY
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THE SCOTTISH NATURALIST

Volume 105

1993

THE SCOTTISH NATURALIST

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A Journal of Scottish Natural History

With which is incorporated *The Annals of Scottish Natural History*
and *The Western Naturalist*

105th Year 1993

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ON

LOCH NESS RESEARCH

initiated by the

LOCH NESS AND MORAR PROJECT

Published by The Scottish Natural History Library

BFN 28630
AN 412368

EDITORS

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ISSN 0268-3385

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By ADRIAN J. SHINE
Loch Ness and Morar Project

JOHN MINSHULL
Loch Ness and Morar Project

and MARALYN SHINE
Loch Ness and Morar Project

Pioneer Work

It is now some ninety years since Sir John Murray and Laurence Pullar published the first part of their pioneer hydrographic survey of Loch Ness (Murray and Pullar, 1903-08), followed by their comprehensive account of all the important Scottish fresh-water lochs (Murray and Pullar, 1910). Then E.R. Watson and James Wedderburn's discovery of internal seiches in Loch Ness (Watson, 1904; Wedderburn, 1907a and 1907b; Wedderburn and Watson, 1909) began a long tradition of physical limnology (e.g. Wedderburn, 1907b, 1911 and 1912) which was ultimately to attract other leading scientists, such as C.H. Mortimer (Mortimer, 1952 and 1955) and S.A. Thorpe (Thorpe, Hall and Crofts, 1972; Thorpe, 1974 and 1988), to this fascinating body of water.

Nevertheless, apart from the pioneer work of the *Bathymetrical Survey*, the biology of the loch remained rather neglected until Dr. Peter Maitland's multi-disciplinary survey of 1977-80 (Maitland, 1981), which has remained the definitive background for further studies.

1993

This year (1993) also marks two other anniversaries. It is now 125 years since the *Inverness Courier* (8th October 1868) first referred to the loch's unusual tradition, and sixty years since the same newspaper (Anon., 1933) coined the term 'Monster'. This tradition has been blamed, possibly somewhat unjustly, for scientific reticence regarding the loch. In fact, as the roll of distinguished scientists shows, this is hardly the case, but equally it remains to be explained why Britain's premier body of fresh-water has not received more attention. Perhaps one reason

has been the inadequacy of much freshwater sampling equipment when confronted with windy surface conditions and water depths of over 200 metres.

The Monster Tradition

On the other hand, although the Monster tradition may have attracted enthusiastic amateur naturalists but few professional zoologists, it did attract trained engineers, and with them some quite large-scale expeditions to provide the logistics for the novel methods of protracted acoustic and underwater camera monitoring (e.g. Campbell and Solomon, 1972; Mackal, 1976; Rines, Wyckoff, Edgerton and Klein, 1976; Rines, 1988). It was from here that the Loch Ness and Morar Project's tradition of improvisation developed, and, as the general scientific possibilities became clear, so some marine equipment found its first freshwater use in Loch Ness (Note 1).

Finally, the opportunity afforded by the Caledonian Canal was exploited, as a collaboration with the Simrad Company and the Department of Agriculture and Fisheries for Scotland (Shine and Martin, 1988); this saw larger vessels entering the loch, thus partly off-setting the hostile surface conditions. None of this would have been possible without a considerable change in general scientific outlook and perspective.

The Parting of the Ways

In 1960 one of the earliest investigators, Dr. Peter Baker, was already attempting to assess the fish population by acoustics, and was speculating about the effects of the loch physics upon the horizontal transport of biomass (Baker and Westwood, 1960; Baker, 1962). However, events in the 1970s, leading to the naming of the Monster as *Nessiteras rhombopteryx* (Scott and Rines, 1975), severed any real connection between aquatic science and popular expectations (Witchell, 1975: 147-156; Witchell, 1989: 139-146).

The Project in the 1980s

The activities of the Loch Ness and Morar Project in the 1980s sought to revise these expectations, through the reintroduction of general scientific objectives, and in 1987 analysis of unusual sonar contacts culminated in 'Operation Deepscan' (Shine and Martin, 1988) and the slaying of the popular media Monster.

Since then, the Project has been given a headquarters at the loch-side by the Official Loch Ness Exhibition Centre, whose proprietor Mr. R.A. Bremner has also generously provided a laboratory, harbour facilities, and land for a field station. This permanent presence has permitted the Project to invite and encourage trained scientific workers from all limnological disciplines to collaborate and take advantage of our field-work and equipment specially developed for deep-water research.

Ecos

A 34-ft clinker-built motor cruiser was purchased in the autumn of 1989. It was originally built in the 1930s as a mail boat for the Orkneys. Renamed *Ecos*, it was renovated and specially adapted for freshwater research (Figure 1). The vessel was selected as particularly suitable because of the open cockpit close to the waterline for easy recovery of equipment and samples. It also has a flush deck giving the necessary space for the hand-hauling of over 100 km of ropes during sampling, trawling, dredging and coring over the last three years (Figure 2). Internally, bench space was provided to mount the bulky instrumentation necessary, for example, for acoustic fish stock surveys. Externally, an out-rigger system permits the rapid over-side deployment of heavy transducers, to port and starboard.

Fixed Station

A fixed station facility was constructed in mid-loch, consisting of a submerged two-point mooring laid in 200 m depth of water. This involves 1.0 km of warp, and permits *Ecos* to maintain station without drift while accurate series of vertical samples are taken.

Over 14 tonnes of water have been raised from the station during continuous studies over the past three summers and two winters. The mooring has also enabled instrumentation, such as thermistors and sediment traps, to be maintained and serviced in deep water.

Coring Equipment

The Project has designed and built its own gravity-coring apparatus for deep-water and for use from smaller vessels. The wide bore (10.3 cm) was originally developed to collect the large volumes of sediment necessary to detect chemicals present at minute concentrations (Sanders, Jones and Shine, 1993). However, the system has proved very effective for quantitative benthos studies (Martin, Shine and Duncan, 1993; Griffiths and Martin, 1993) as well as sediment mapping

Figure 1

ECOS

(See page 9)

Figure 2

Hand-hauling some of the 100 km of ropes

(See page 9)

(Bennett and Shine, 1993). Very satisfactory 3.0 m cores can be taken with this system.

Personnel

The authors provide a permanent loch-side presence to conduct field-work. In London, David Martin acts as a scientific clearing house for materials destined for specialist workers elsewhere. Each year, volunteers are recruited and logistics organised to support the various programmes. These volunteers are mainly students, some in the course of B.Sc. dissertations, but other volunteers come from all walks of life.

Recent Increase in Research

During the past three years it is gratifying to report that forty collaborators have responded with research on many aspects of Loch Ness, including a continuous three-year multi-disciplinary plankton study by the University of Lancaster, to which the Project has contributed the field-work (see Appendix). At least seventeen B.Sc., M.Sc., M.Phil. and Ph.D. dissertations and theses, wholly or partly devoted to the loch, have been completed or are in preparation (see Appendix), and the Project's Sediment Group is also being co-ordinated by the Environmental Change Research Centre at University College London.

During 1992 and 1993 a certain amount of material was presented at meetings of the Institute of Fisheries Management (Note 2), the Societas Internationalis Limnologae Theoreticae et Applicatatae (S.I.L.S.) in Barcelona (Note 3), and the British Ecological Society (Note 4); further papers and posters featured in the 50th meetings of both the Scottish (Note 5) and London (Note 6) Freshwater Groups. Additional specialist publications will follow in due course, but clearly it is now time to place some collected observations on record in order to emphasise some aspects of recent work which are regarded as particularly interesting, and to pose a few questions.

Project Contributions

The place of Loch Ness in relation to the other major Scottish lochs has already been set out in detail by Maitland (1981). In terms of richness and diversity, Loch Ness was found to be generally intermediate between the 'richest', Loch Awe and Loch Lomond, and the 'poorest', Loch Morar and Loch Shiel. In the main, the Loch Ness and Morar Project has applied its energies to carrying out work complementary to several aspects of Dr. Maitland's studies.

Sediments

Following a hydrographic and seismic survey (Young and Shine, 1993), sediment studies have been conducted in detail and have produced answers to the questions of acidification, eutrophication and pollution (Jones, Rose and Appleby - Notes 4 and 5; Bennett and Shine, 1993; Jenkins, 1993a; Sanders, Jones and Shine, 1993). Much additional work is being undertaken as longer cores are obtained.

The Littoral

The littoral of Loch Ness is a steeply sloping stony ribbon exposed to considerable wave action. Examination of the sub-littoral macrophytes, by underwater television, confirms the low light penetration, the *Isoetes* swards of more transparent lochs, such as Morar, being replaced by strands of filamentous algae. The chemistry of feeder streams has been examined by Jenkins (1993b).

The invertebrates of the littoral (<1.0 m) were extensively surveyed by Smith, Maitland, Young and Carr (1981). The Project's attentions have therefore been restricted to sub-littoral invertebrate sampling, for comparison with the profundal.

The fish of the littoral are described by Shine, Kubecka, Martin and Duncan (1993).

The Profundal

In terms of basic species lists, the only significant gap in the Institute of Terrestrial Ecology's comprehensive survey (Maitland, 1981) was the profundal region, the size of which is very considerable in Loch Ness because of the loch's great mean depth (132 m). The Project's contribution (Martin, Shine and Duncan, 1993) now fills this gap.

Ongoing work with a quantitative wide-bore coring technique is now defining community structures and densities in a way similar to that achieved for the ostracods (Griffiths and Martin, 1993). In the future, the life history of some of the chironomids seems worth examination, since they contribute to the diet of profundal Charr as larvae and to that of pelagic Charr as pupae. It is particularly important to follow the pattern of their emergence and behaviour in the pelagic at this time, when they are sometimes associated with acoustic scattering layers.

An interesting discovery during the profundal programme was a population of Charr ranging in size between 4.0 cm and 30 cm. These are described by Shine, Kubecka, Martin and Duncan (1993).

The Pelagic

The pelagic zone has been the main area for the Loch Ness and Morar Project's contributions to Loch Ness research, because of its amenability to investigation by acoustic methods (Kubecka, Duncan and Butterworth, 1993; Shine, Martin and Marjoram, 1993).

Physical Characteristics of Loch Ness

The regular morphometry and orientation of Loch Ness, in line with the prevailing south-west wind, has produced a dynamic physical environment (Shine and Martin, 1988). Powerful wind mixing often extends deep into the water column. This, together with low light penetration and scarce nutrients, reduces the scope of primary productivity, and the importance of microbial productivity is therefore enhanced (Shine, Martin, Bennett and Marjoram, 1993).

Investigations

The balance between algae and bacteria, together with nutrient and carbon flow, should soon become clear as the Project enters the last of three years of sampling on behalf of the University of Lancaster's plankton survey, funded by the Natural Environment Research Council (N.E.R.C.) (see Appendix).

In addition to the above acoustic studies, the pelagic fish are described by Shine, Kubecka, Martin and Duncan (1993) and Martin and Shine (1993).

Further efforts will be made to explore links between vertical migration and predator-prey relationships in the fish and zooplankton. The components of the scattering layer also need to be further resolved, and the behaviour of chironomid pupae examined.

Acknowledgements

The work described in this paper was made possible by the enthusiasm of the volunteer members of the Loch Ness and Morar Project over the last three years. Particular thanks are due to the following, who have given considerable time in

staff roles during the field-work: Miss S. Bennett, Mrs E. Gallagher, Mr. K. Hawley, Mr. B. Herring, Miss R.S. Marjoram, Mr. James Reid, Mr. P. Rimmer, Mr. J. Vallette, and Mr. K. Wilson.

Notes

Note 1

The 200 m depth of the loch has been exploited in trials of a variety of marine equipment, including Remote Operated Vehicles (R.O.V.s). Conversely, water of this depth demands equipment with marine capabilities, such as underwater television and cameras; marine sonars have also been brought in for hydrography and acoustic fish estimates. It has also been possible to use large hull-mounted units, as vessels are able to enter the loch via the Caledonian Canal.

Note 2

Institute of Fisheries Management, Greater London and South-East Branch. Branch Meeting, King's College, London, 3rd March 1992.

Paper read. The Fish and Other Fauna of Loch Ness. By Annie Duncan and J. Kubecka (Department of Biology, Royal Holloway University of London) and D.S. Martin and A.J. Shine (Loch Ness and Morar Project).

Note 3

Societas Internationalis Limnologae Theoreticae et Applicatatae. XXV International Congress, University of Barcelona, Spain, 21st-27th August 1992.

Poster paper. Longitudinal and Vertical Patterns of Pelagic Fish Distribution in Loch Ness: Acoustic Sizes and Numbers. By Annie Duncan and J. Kubecka (Department of Biology, Royal Holloway University of London) and A.J. Butterworth (National Rivers Authority, Thames Region).

Poster papers. Studies of the Plankton of Loch Ness. By R.I. Jones, Johanna Laybourn-Parry, M. Walton and Judith M. Young (Institute of Environmental and Biological Sciences, University of Lancaster), and A.E. Bailey-Watts (Institute of Freshwater Ecology, Penicuick, Midlothian).

1) Phytoplankton. By Judith M. Young, R.I. Jones, and A.E. Bailey-Watts.
2) The Microbial Loop. By Johanna Laybourn-Parry and M. Walton.
3) Rotifers. By Alison Fulcher.

Later published as abstracts: 1 - Young, Jones and Bailey-Watts (1993); 2 - Laybourn-Parry and Walton (1993); 3 - Fulcher (1993).

Note 4

British Ecological Society. Winter meeting and A.G.M., University of Lancaster, 15th-17th December 1992.

Paper read. Functional Aspects of the Microbial Plankton in Loch Ness. By M. Walton and Johanna Laybourn-Parry (Institute of Environmental and Biological Sciences, University of Lancester).

Paper read. Bioassay Studies of Loch Ness Phytoplankton. By R.I. Jones and Anne Hartley (Institute of Environmental and Biological Sciences, University of Lancaster).

Paper read. Dual-beam Echo-sounding for Fish in Loch Ness. By Annie Duncan and J. Kubecka (Department of Biology, Royal Holloway University of London).

Paper read. Picophytoplankton of Loch Ness, a Deep Oligotrophic Lake. By Judith M. Young and R.I. Jones (Institute of Environmental and Biological Sciences, University of Lancaster.

Institute of Environmental and Biological Sciences, University of Lancaster.
Poster papers: Studies of the Plankton of Loch Ness.

1) Phytoplankton. By Judith M. Young and R.I. Jones.
2) The Microbial Loop. By Johanna Laybourn-Parry and M. Walton.
3) Rotifers. By Alison Fulcher.
4) Crustacean Zooplankton. By U. Jayakodi.

Later published as abstracts: 1 - Young, Jones and Bailey-Watts (1993); 2 - Laybourn-Parry and Walton (1993); 3 - Fulcher (1993).

Poster paper. The Recent History of Loch Ness. By Vivienne Jones and N. Rose (Environmental Change Research Centre, University College London) and P.G. Appleby (University of Liverpool).

Poster paper. Longitudinal and Vertical Patterns of Pelagic Fish Distribution in Loch Ness: Acoustic sizes and Numbers. By Annie Duncan and J. Kubecka (Department of Biology, Royal Holloway University of London) and A.J. Butterworth (National Rivers Authority, Thames Region).

Poster paper. Profundal Benthos in Loch Ness. By D.S. Martin and A.J. Shine (Loch Ness and Morar Project) and Annie Duncan (Department of Biology, Royal Holloway University of London).

Poster paper. Loch Ness Project, Reviews and Previews. By A.J. Shine (Loch Ness and Morar Project).

Poster paper. Loch Ness Undercurrents 1 and 2. By A.J. Shine (Loch Ness and Morar Project).

Note 5

Scottish Freshwater Group. 50th Meeting, University of Stirling, 2nd-3rd February 1993.

Institute of Environmental and Biological Sciences, University of Lancaster.

Poster papers: Studies of the Plankton of Loch Ness.

1) Phytoplankton. By Judith M. Young and R.I. Jones.
2) The Microbial Loop. By Johanna Laybourn-Parry and M. Walton.
3) Rotifers. By Alison Fulcher.
4) Crustacean Zooplankton. By U. Jayakodi.

Later published as abstracts: 1 - Young, Jones and Bailey-Watts (1993); 2 - Laybourn-Parry and Walton (1993); 3 - Fulcher (1993).

Poster paper. The Recent History of Loch Ness. By Vivienne Jones and N. Rose (Environmental Change Research Centre, University College London) and P.G. Appleby (University of Liverpool).

Poster paper. Application of Hydroacoustics to Scottish Freshwaters: Case Studies in Loch Ness and Orkney Lochs. By Annie Duncan and J. Kubecka (Department of Biology, Royal Holloway University of London) and A.J. Butterworth and W. Duncan (National Rivers Authority, Thames Region).

Poster paper. Profundal Benthos in Loch Ness. By D.S. Martin and A.J. Shine (Loch Ness and Morar Project) and Annie Duncan (Department of Biology, Royal Holloway University of London).

Poster paper. Loch Ness Project, Reviews and Previews. By A.J. Shine (Loch Ness and Morar Project).

Poster paper. Loch Ness Undercurrents 1 and 2. By A.J. Shine (Loch Ness and Morar Project).

Note 6

London Freshwater Group. 50th Meeting, Linnean Society, London, 19th March 1993.

Paper read. The Biology of Loch Ness. By D.S. Martin (Loch Ness and Morar Project).

Appendix

Research work carried out at Loch Ness towards the degrees of B.Sc., M.Sc., M.Phil. or Ph.D. include the following:

Baker, D.L. (1993). *A Palaeolimnological Reconstruction of the Recent History of the Catchment of a Scottish Loch.* B.Sc. Dissertation, University of Wolverhampton.

Bennett, S. (1993). *Patterns and Processes of Sedimentation in Loch Ness.* B.Sc. Dissertation, University of Staffordshire.

Bracewell, C.E. (1993). *A Geochemical Study of Natural and Pollutant Compounds in Loch Ness, Scotland.* M.Sc. Dissertation, University of Newcastle-upon-Tyne.

Fulcher, A.S. (Ongoing). *Rotifers of Loch Ness and the Cumbrian Lakes.* Ph.D. Thesis, University of Lancaster.

Griffiths, H.I. (Ongoing). *Applications of Freshwater Ostracods in the Study of Late Quaternary Palaeoenvironments of North Western Europe.* Ph.D. Thesis, University of Cardiff.

Hartley, A. (1993). *Plankton Bioassay of Loch Ness Water.* B.Sc. Dissertation, University of Lancaster. *

Jayakodi, U. (Ongoing). *The Ecology of Zooplankton in Loch Ness.* Ph.D. Thesis, University of Lancaster. *

Jenkins, P.H. (Ongoing). *Comparative Effects of Environmental Change, Human Impact and Climatic Change on a Large and Small Lake.* Ph.D. Thesis, University of Wolverhampton.

Mansfield, C.A. (1992). *A Study of Biogenic and Anthropogenic Compounds in Sediment Cores from Loch Ness, Scotland.* M.Sc. Dissertation, University of Newcastle-upon-Tyne.

Marjoram, R.S. (1993). *An Investigation of the Identification and Behaviour of an Acoustic Scattering Layer in Loch Ness, Scotland.* B.Sc. Dissertation, Worcester College of Higher Education.

Meacham, N.J. (1993). *The Fecundity and Associated Ecological Factors of the Arctic Charr, Salvelinus alpinus, and Brown Trout, Salmo trutta, in Loch Ness, Scotland.* B.Sc. Dissertation, University of Hull.

Miller, K.C. (1993). *A Study of Sedimentary Markers within the Lacustrine Environment.* B.Sc. Dissertation, University of Edinburgh.

Millward, D. (1992). *A Palynological Sedimentation Study of a Core from the South Basin of Loch Ness.* B.Sc. Dissertation, University of Hull.

Picots, A. (Ongoing). *Studies of Bacterioplankton in Loch Ness, plus Limiting Factors.* M.Sc. Dissertation, University of Lancaster.

Walton, M. (Ongoing). *The Population Dynamics of Bacteria and Flagellated Protozoa in Loch Ness.* Ph.D. Thesis, University of Lancaster. *

Wheeler, A. (Ongoing). *Structure, Origin and Periodicity of Laminations in Holocene Sediment Cores from Loch Ness, Scottish Highlands.* Ph.D. Thesis, University of Wolverhampton.

Young, J.M. (Ongoing). *Picoplankton in Loch Ness.* M.Phil. Dissertation, University of Lancaster. *

* Research carried out under the auspices of the University of Lancaster's multi-disciplinary plankton study - Plankton Community Dynamics of a Large Oligotrophic Freshwater System (Loch Ness) - funded by the Natural Environment Research Council (N.E.R.C.).

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Received July 1993

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LOCH NESS BATHYMETRIC AND SEISMIC SURVEY, December 1991

By IAN YOUNG
Bentech Subsea A/S

and ADRIAN J. SHINE
Loch Ness and Morar Project

Introduction

The status of Loch Ness as Britain's greatest body of fresh-water was established by Murray and Pullar (1903-08 and 1910) during their *Bathymetrical Survey of the Scottish Fresh-water Lochs*. A Pullar wire sounding machine (Figure 1) was used in April 1903, and 1,700 soundings were taken from a rowing boat in a series of across-loch transects. This revealed a steep-sided, flat-bottomed trench-like profile resulting from the Great Glen's tectonic origins. Thus, despite being second to Loch Morar (310 m) in maximum depth, Loch Ness (maximum depth 230 m) has the greatest mean depth (132 m) and hence the greatest volume ($74.52\ m^3 \times 10^8$) of all British lakes.

A controversy about the maximum depth occurred in 1969 during the trials of the Vickers *Pisces* submersible. Reports claimed that the *Pisces* had descended to 820 feet (250 m) and that a sonar depth of 970 feet (295 m) had been obtained at a position a quarter of a mile south of Urquhart Castle (Eastaugh, 1970).

An attempt to resolve this was made in 1979 by the Loch Ness and Morar Project (L.N.M.P.), using a Kelvin Hughes MS48 single beam echo-sounder. A search pattern failed to register depths in excess of 225 m (Shine and Martin, 1988).

The introduction of 'swathe' sounding systems (a fan of multiple beams) in the 1980s greatly reduced survey time, and the first use at Loch Ness was in a survey of Urquhart Bay using a Simrad EM100 in 1987 (Shine and Martin, 1988).

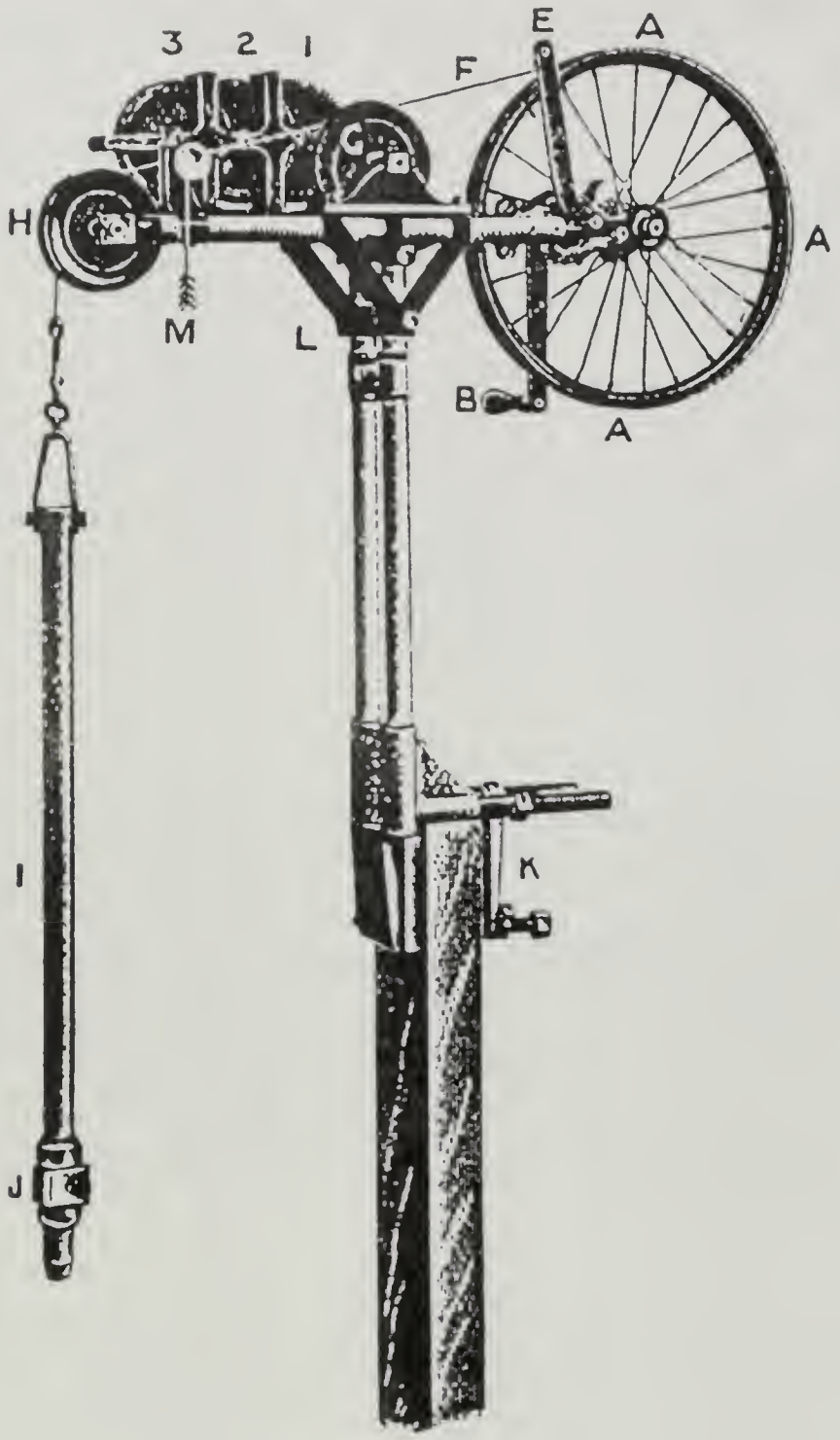


Figure 1

The Pullar Wire Sounding Machine

Used in the 1903 survey and illustrated in the

Bathymetrical Survey of the Scottish Fresh-Water Lochs

(1910)

The 1991 survey was designed to resolve any remaining controversy over the maximum depth of Loch Ness, and in particular to prepare for the L.N.M.P.'s deep-coring programme (the 'Rosetta' project, see Note 1).

Methods

Precision echo-sounding relies on an accurate knowledge of the sound velocity profile, and this was a major concern for the survey. The complex internal seiches known to exist in Loch Ness during the summer create unpredictable and complex velocity profiles and refractions which are subject to rapid change and cycling (Shine and Martin, 1988).

Conversely, the loch is largely isothermal in the winter, so this was chosen as the optimum time for the 1991 bathymetric survey. The velocity profiles taken during the survey confirmed this, and clearly show the uniform and stable profile (Figure 2).

The hydrographic system used was the Bentech TOPAS, i.e. parametric topography and seismic profiling sonar. The PS40 parasource had a 24-stave transducer with a primary frequency of 40 kHz and a secondary frequency of 1.0-10 kHz. Electronic sequential scanning enabled high speed collection of echo-soundings across a selected swathe of 40° perpendicular to the survey vessel's line of travel (Figure 3).

Information was monitored on surface displays for bathymetry and seismics. Navigational and sonar measurements were integrated through an RS232 data link. Data were stored on a Bentech D.S.004 EXABYTE unit (2.5 Giga Byte).

For best results the survey was planned from a knowledge of the general topography of the loch, with swathes made roughly perpendicular to the lines of contour. Further knowledge of approximate depths allowed planning of survey lines to maximise the coverage of the loch bed. The deep basins were of primary interest, so survey lines were calculated to provide blanket coverage for all depths below 50 m and a 50% coverage of the rest of the loch.

Because of the very steep side-walls, this in effect represented almost the complete loch. The survey lines were programmed into the computer to provide a display of the survey position and overview online data via a helmsman's 'head up' display (Figure 4).

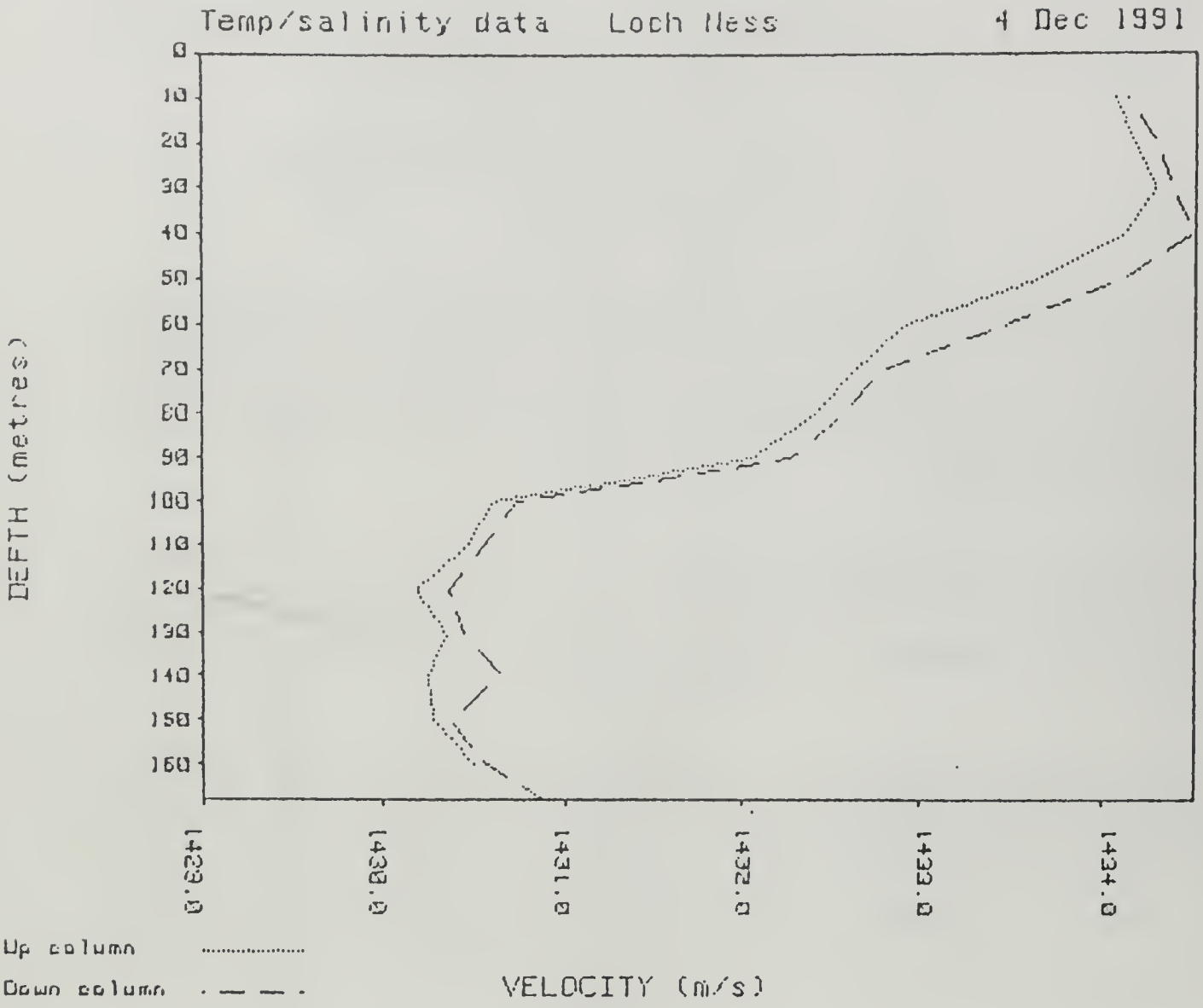


Figure 2

Sound Velocity Profile of Loch Ness, 4.12.91.

Tables/graphs/data - Averages Location: Loch Ness 4 Dec 1991

Between the depths of 10.0 and 168.0 metres:

The Up column average sound velocity is	1432.06	(using 16 readings)
The Down column average sound velocity is	1432.26	(using 16 readings)
The average of the above two values is	1432.16	
The Up column average density is	1.0001	(using 16 readings)
The Down column average density is	1.0001	(using 16 readings)
The average of the above two values is	1.0001	

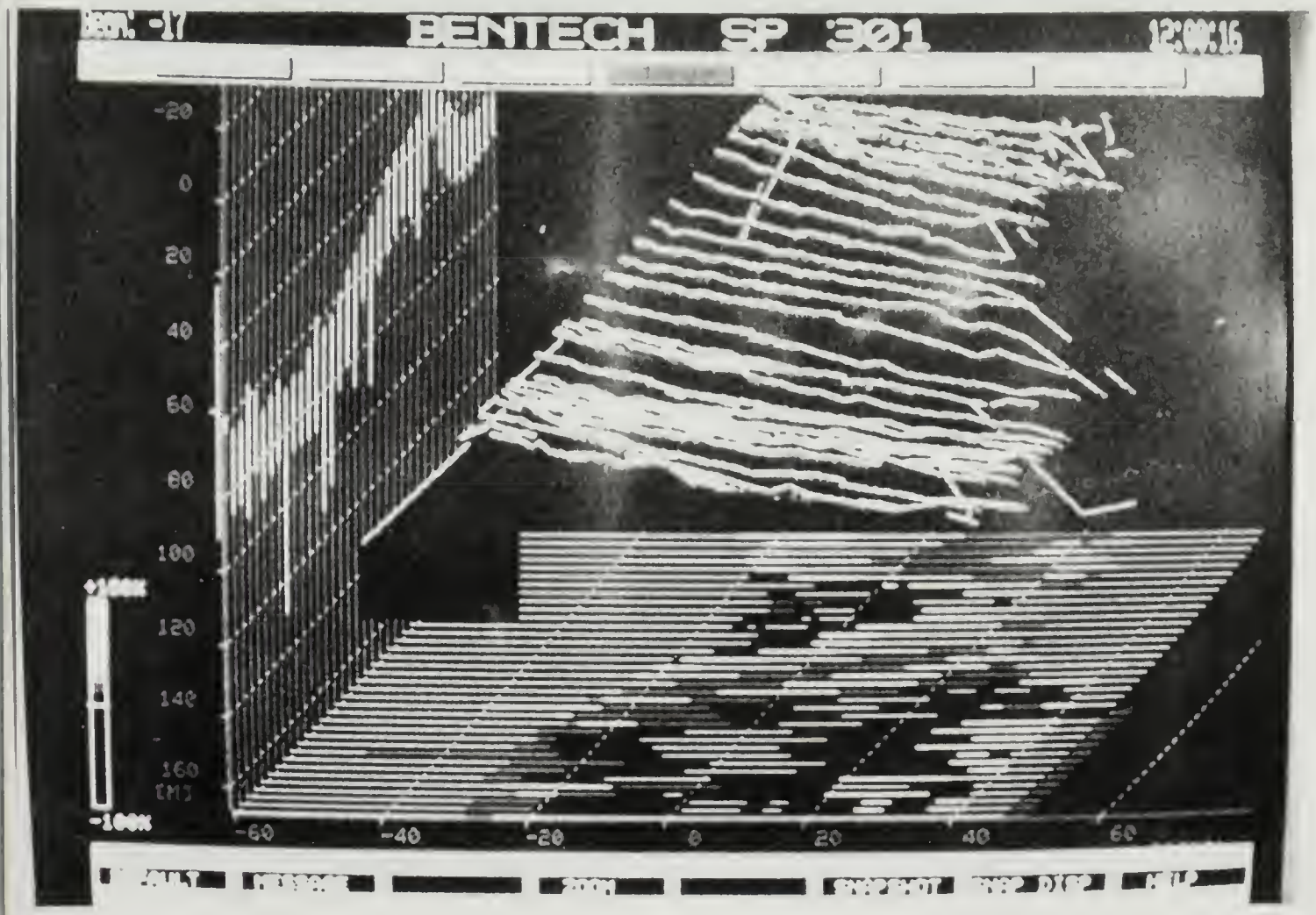


Figure 3

The Bentech TOPAS display shows a real time 'cascade' of soundings across the swathe of coverage.

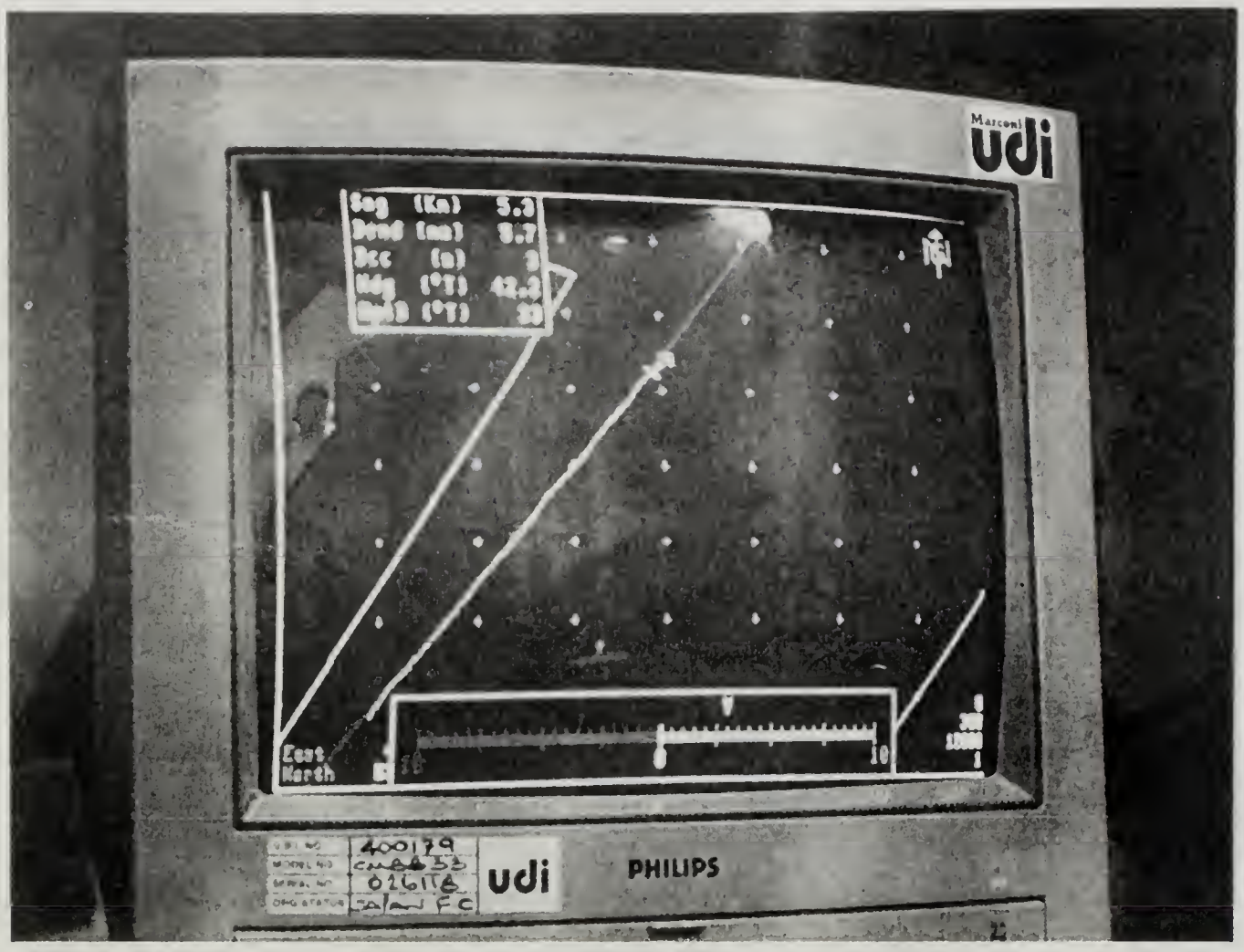


Figure 4

The helmsman's 'head up' display permits the vessel to be steered along the survey lines even in darkness.

The 35-ft survey vessel *Highland Commander II*, supplied by Caley Cruisers of Inverness, demonstrated the capability of the TOPAS to be deployed from a vessel of opportunity, and permitted operation in shallow water. The transducer was fitted to a rigid pole mounted on the side of the vessel, deployed to a depth of 2.0 m below the waterline to avoid cavitation effects and to give the transducer a clear line of sight to the loch bed below the keel.

Navigation equipment supplied by Marconi Udi (Note 2) used the U.S. Department of Defence NAVSTAR global positioning satellites (G.P.S.), the overall accuracy of the system being further enhanced by Marconi Udi's STARTRAK differential G.P.S. system. STARTRAK (Note 3) applies established survey principles of differential correction to the G.P.S. data (± 3.0 m with 1.0 second updates).

These corrections are calculated at a surveyed reference station in Aberdeen, and are transmitted by dual terrestrial private circuit lines to Goonhilly for sending through the Inmarsat standard 'A' communication link to the survey vessel. Inmarsat was chosen as the data link because of its high integrity and rapid data transfer speed.

For vessels of opportunity not fitted with Inmarsat, as in the case of this survey, Marconi Udi provide a Local Extension Service (L.E.S.) from a remote station set up within U.H.F. telemetry link contact with the survey vessel. This receives Inmarsat data and relays it to the survey vessel.

There was also a risk that the Inmarsat transmissions might not be picked up when running survey lines close to the shore, because of the surrounding hills. Prior to the survey, Marconi Udi established workable locations for the remote stations on the loch side.

Survey Operation

The survey was completed in five days between 2nd and 6th December 1991, with the first day being devoted to installation and calibration. The calibration of TOPAS was restricted to alignment of the transducer only, the sonar automatically providing roll compensation.

Days 2-5 were the survey days. Figures 5a to 5d give details of the lines surveyed on each day. The total survey time over the four days was 31 hours, and a total of 288 km of survey was completed at an average survey speed of 5.5 knots. A total of over 200,000 bathymetric soundings and 0.8 Giga Bytes of seismic profile data were recorded.

Figures 5a to 5d

Survey line plots

a. 3.12.91

b. 4.12.91

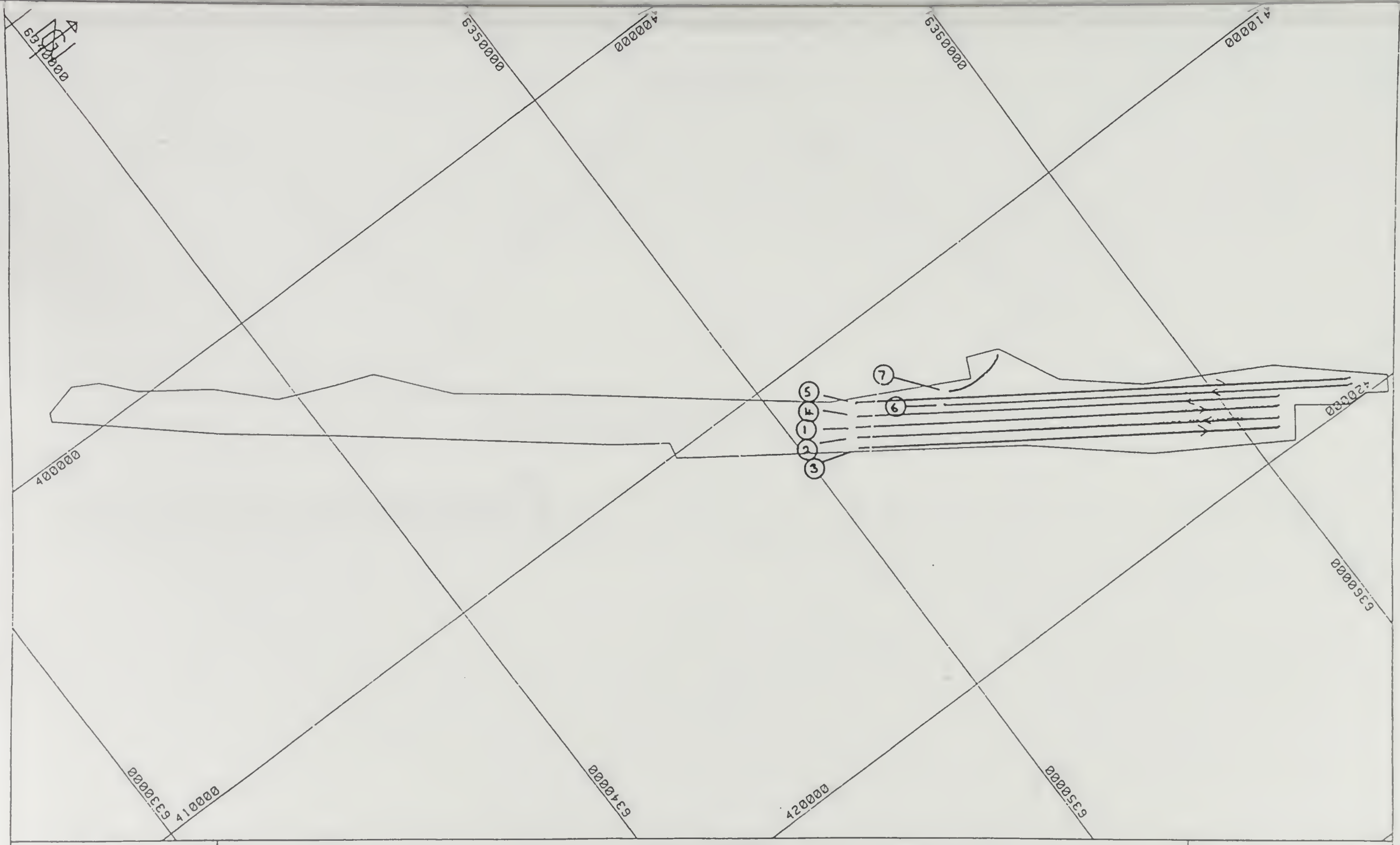
c. 5.12.91

d. 6.12.91

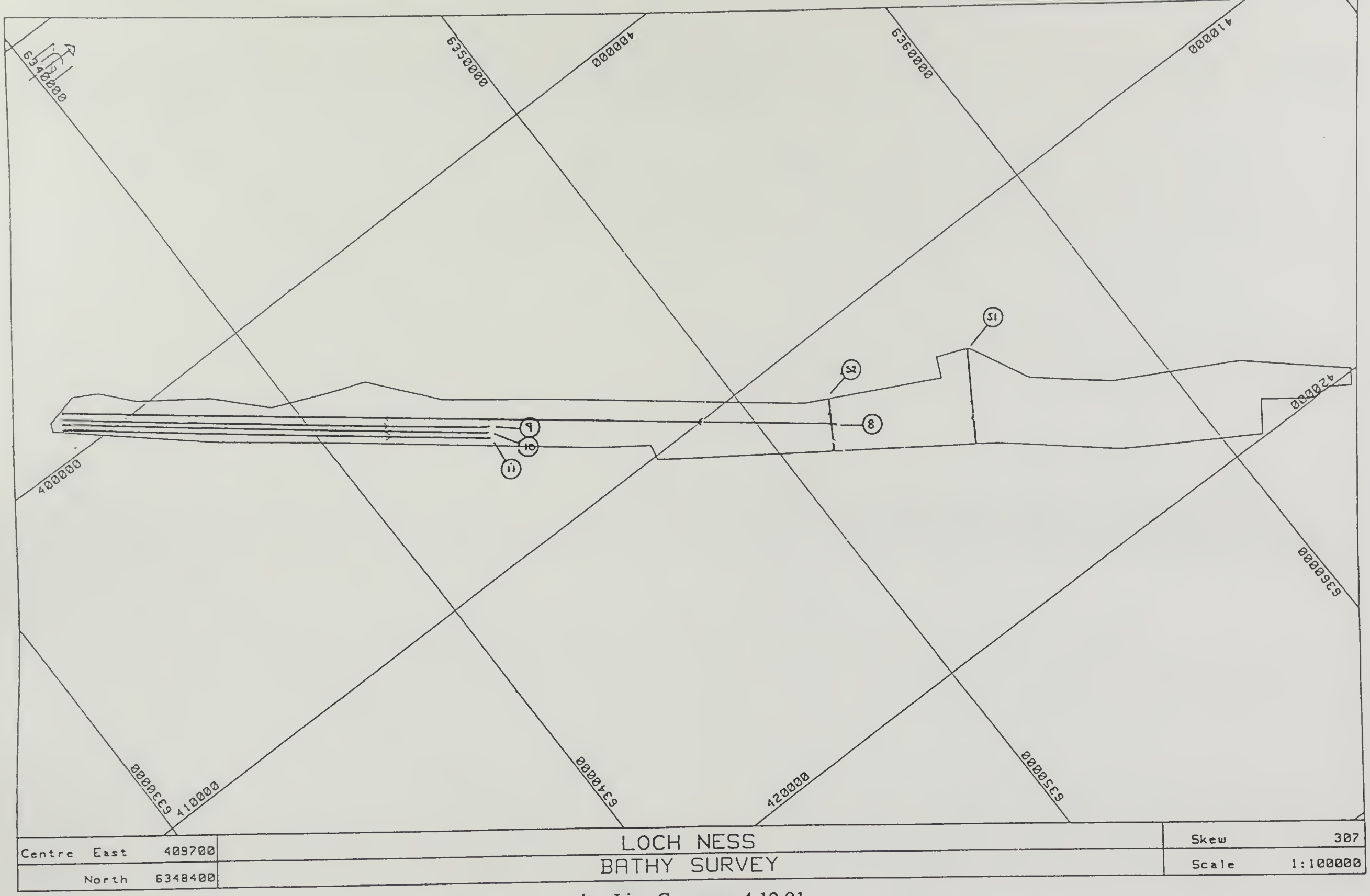
Daily line plots of areas surveyed

Lines 1 -34 : Hydrographic Survey

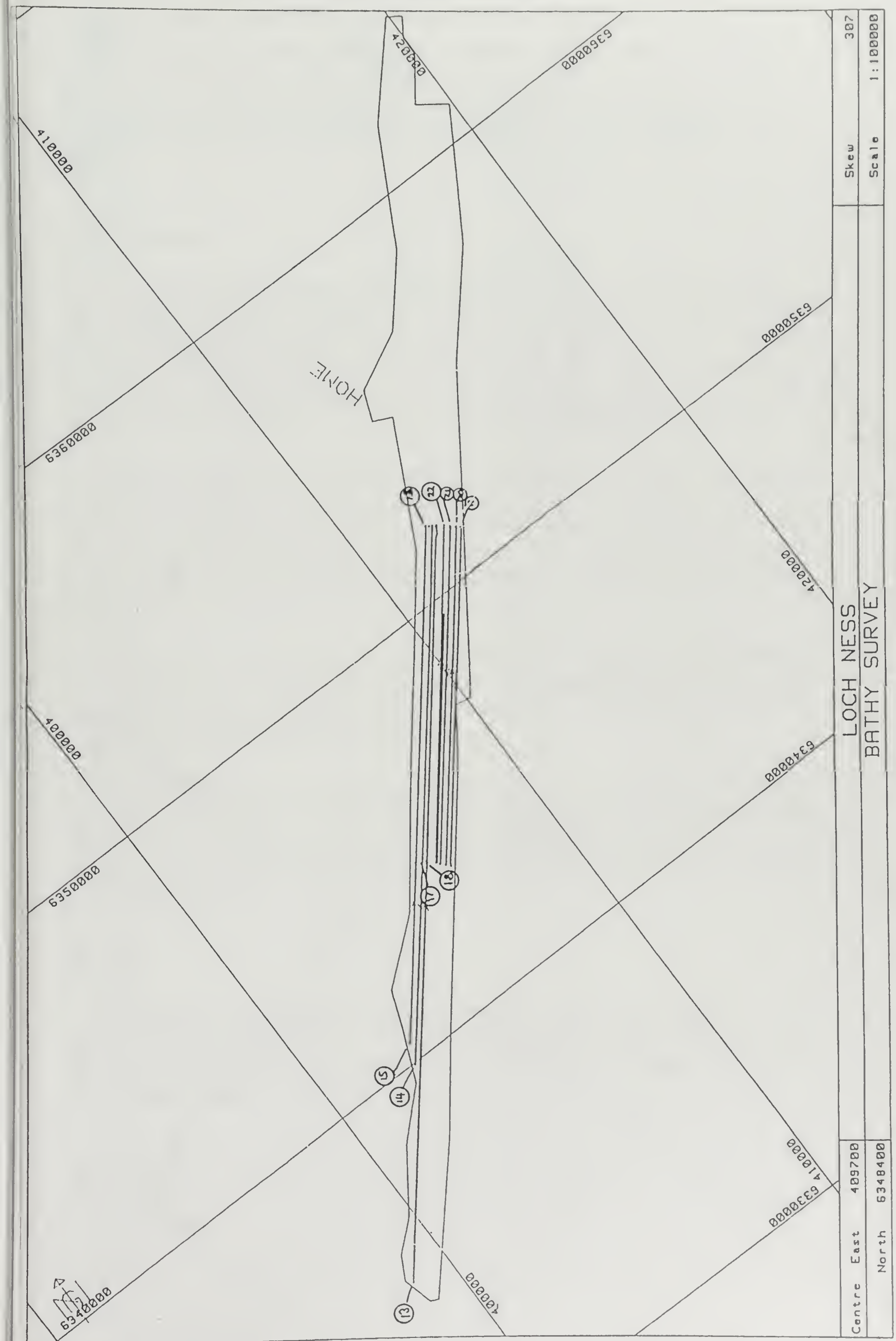
Lines S1-S6 : Seismic Profiles



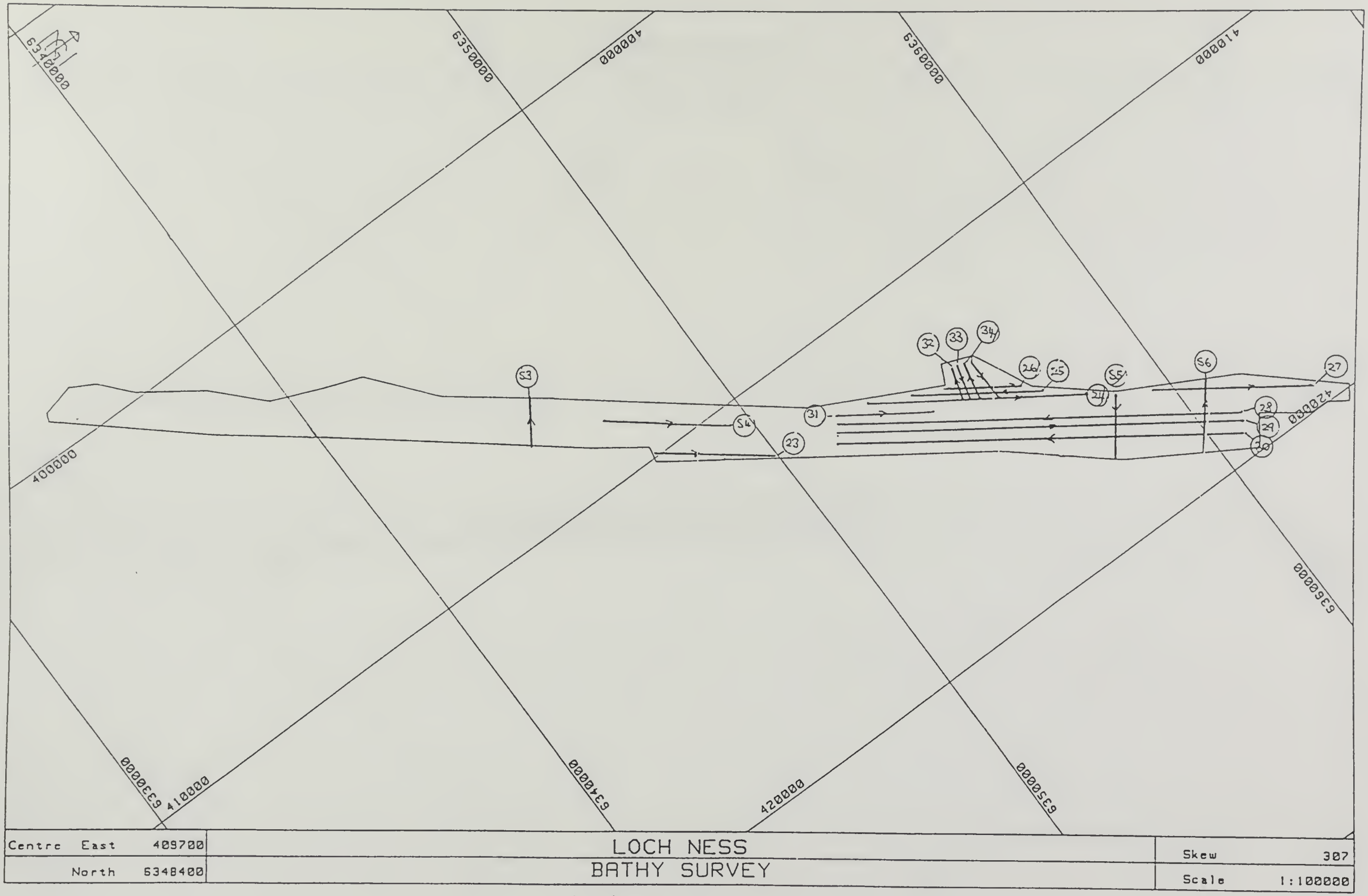
a. Line Coverage 3.12.91



b. Line Coverage 4.12.91



c. Line Coverage 5.12.91



d. Line Coverage 6.12.91

Five across-loch seismic profiles were completed; four in the North Basin and one in the South Basin. Along axis data were also recorded over the rise off the River Foyers. Seismic data apparently in excess of 30 m below the loch bed were recorded (Figures 6a to 6d) and further processing of this data is planned for the future.

Post-Processing

Post-processing of the data was undertaken by Britsurvey, a division of Svitzer. The data set recorded contained a considerable wealth of information, which included the vessel position and approximately 4,000 amplitude sub-samples of each trace. The first task was to extract the loch bed data from the sub-samples. A programme routine was written, to calculate the spatial location of the loch bed index of each ping, and was adjusted for the speed of sound and transducer depth.

The loch level was recorded on each day of the survey, and for comparison purposes the datum was transposed back to the level used by Murray and Pullar (16 m). The resulting output was a concise XYZ data set. To assist with the interpolation of the depths between the shore-line and the limits of the survey, the perimeter of the loch was digitised and an XYZ data set generated with a Z value of zero.

The data set was imported into Britsurvey's CPS-3 mapping package running on a SunSparc work-station. The information was computed onto a 100 m grid using a convergent gridding algorithm. The Z values were then converted to imperial units and contoured at 100 feet intervals.

The resulting chart was transferred to Britsurvey's Autocad system, and plotted at the imperial scale of 1:21,120 (3.0 inches to 1.0 mile) to allow comparisons with the earlier imperial charts produced by Messrs Bartholomew from the Murray and Pullar survey of 1903. Metric charts were also produced with 25 m contour intervals (Figure 7).

Results

The results show a positive similarity between the 1991 survey and the 1903 survey of Murray and Pullar. The general regularity of the loch basin was confirmed. Some of the areas of rocky side-wall caused difficulties acoustically due to local irregular rock facets.

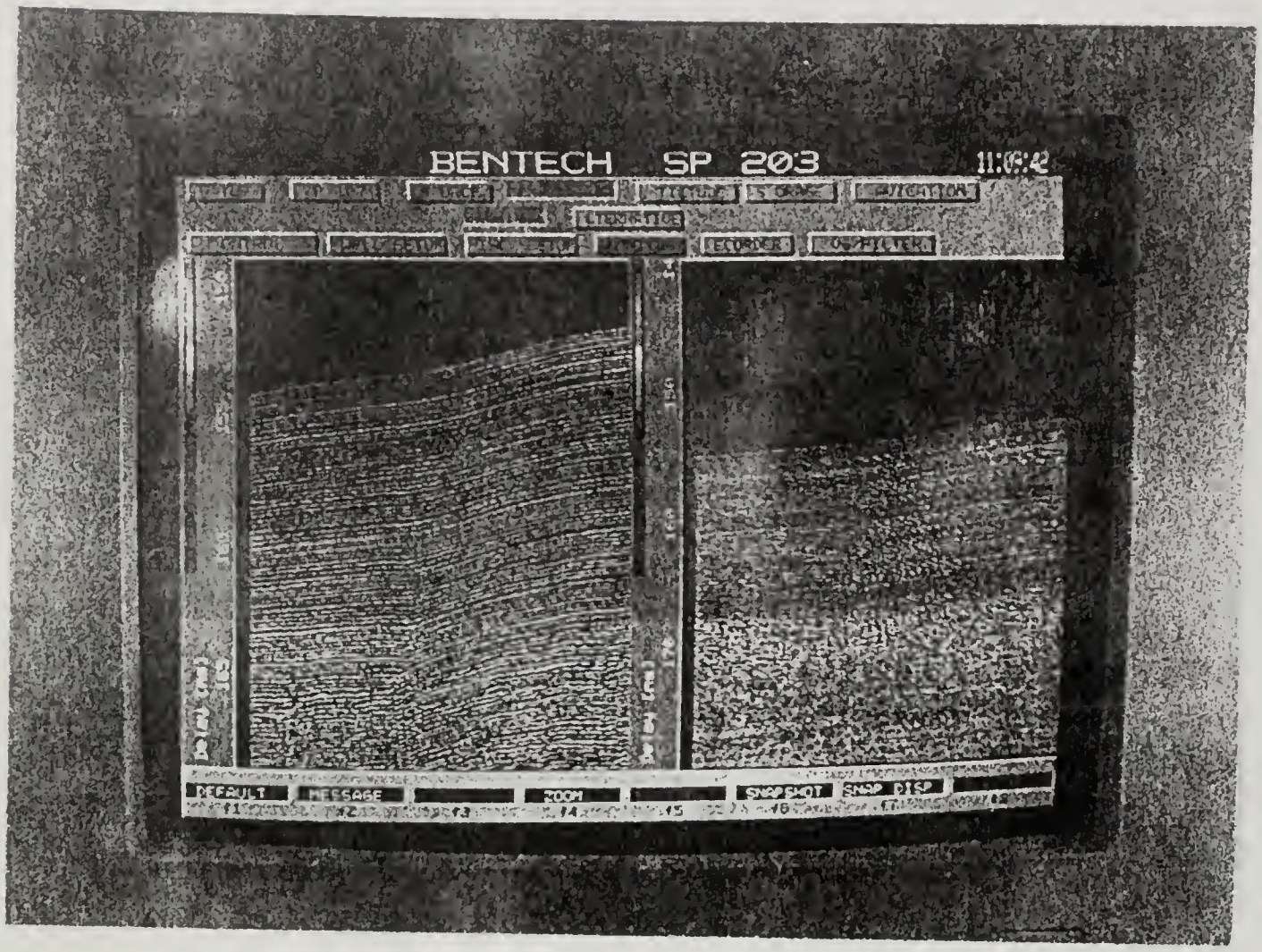


Figure 6a

Bentech TOPAS display of on-line seismic data.

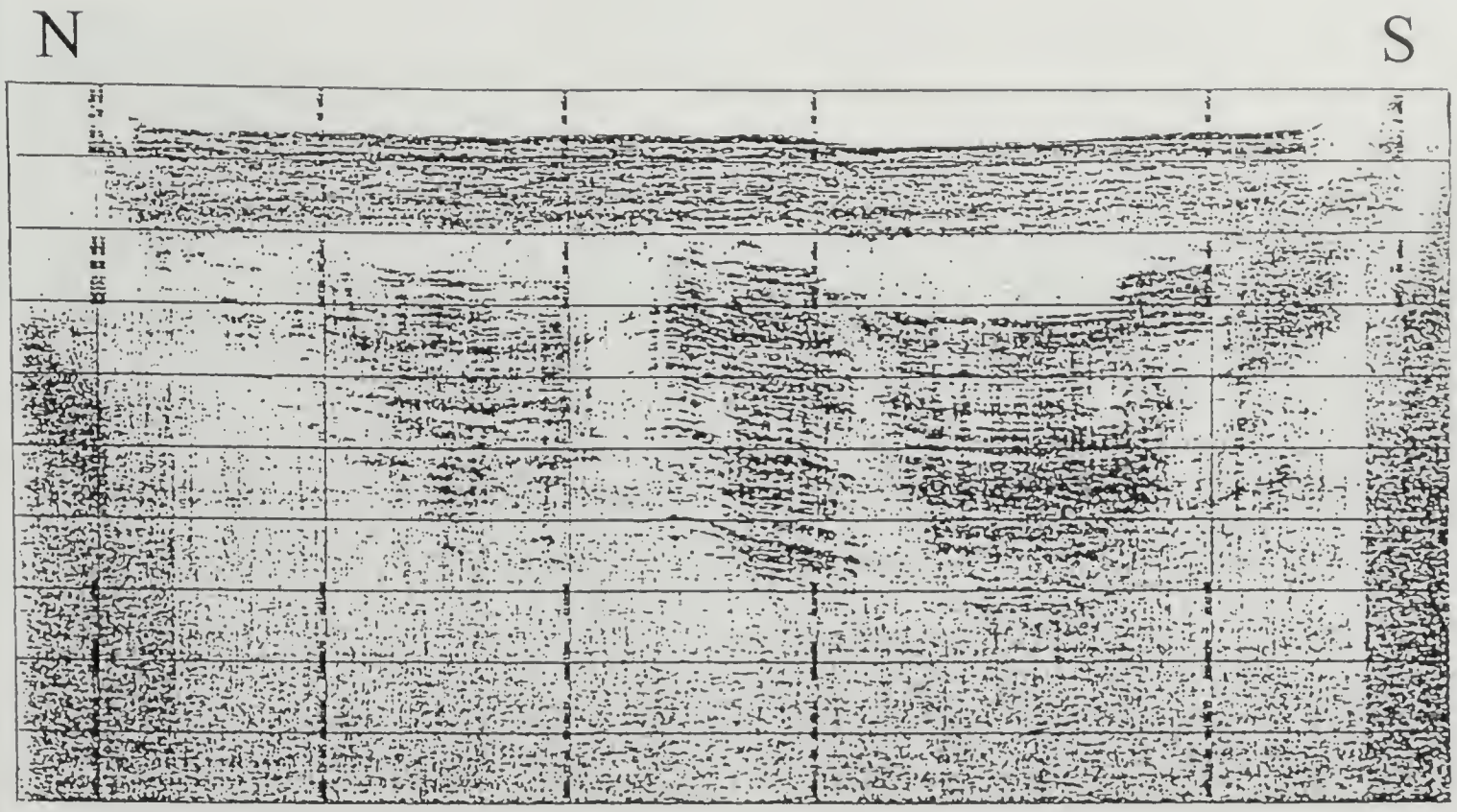


Figure 6b

Seismic profile (line S1) off Urquhart Bay
North to South. Delay: 28 mSec. Sweep: 10 mSec.

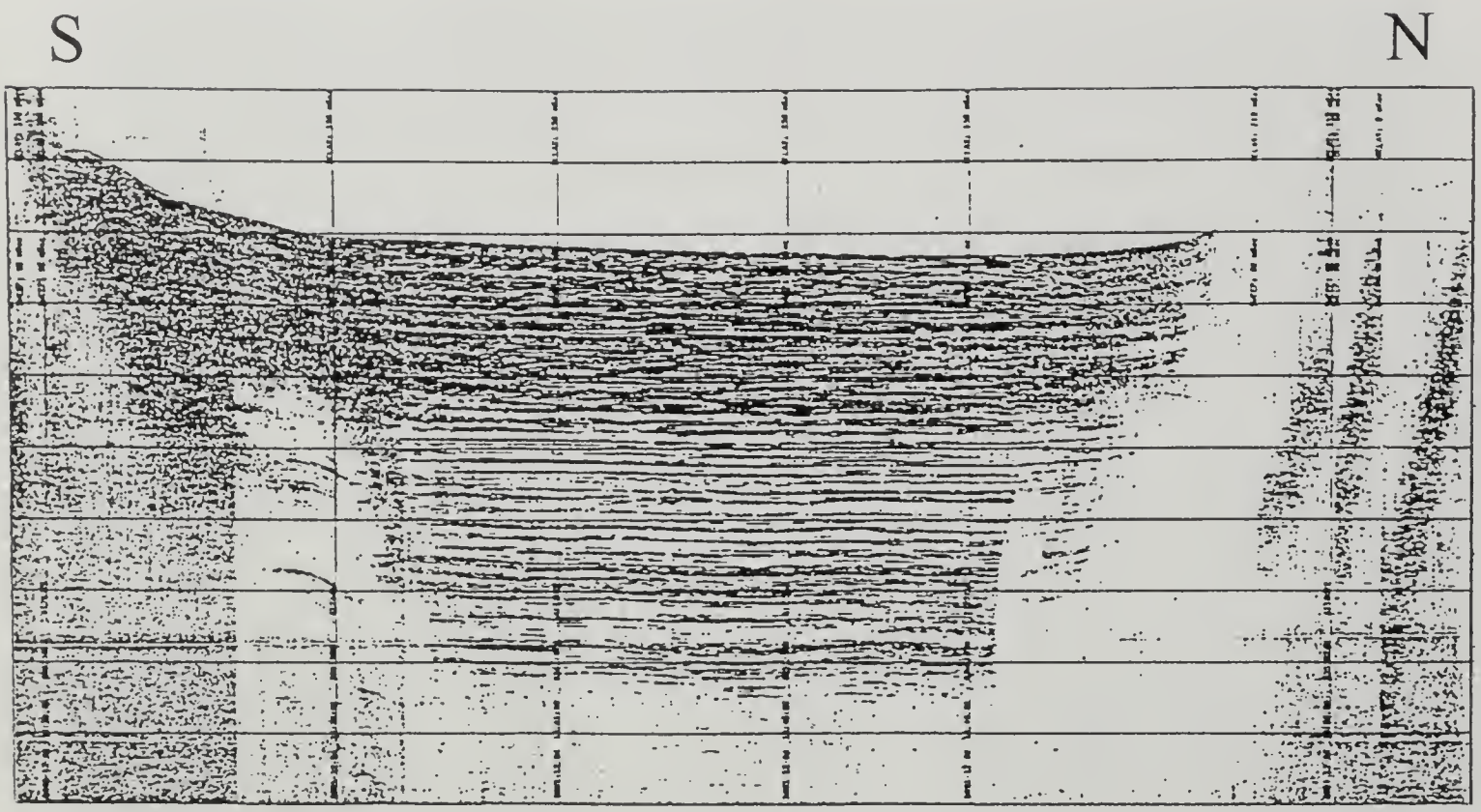


Figure 6c

Seismic profile (line S2) off Achnahannet
South to North. Delay: 28 mSec. Sweep 10 mSec.

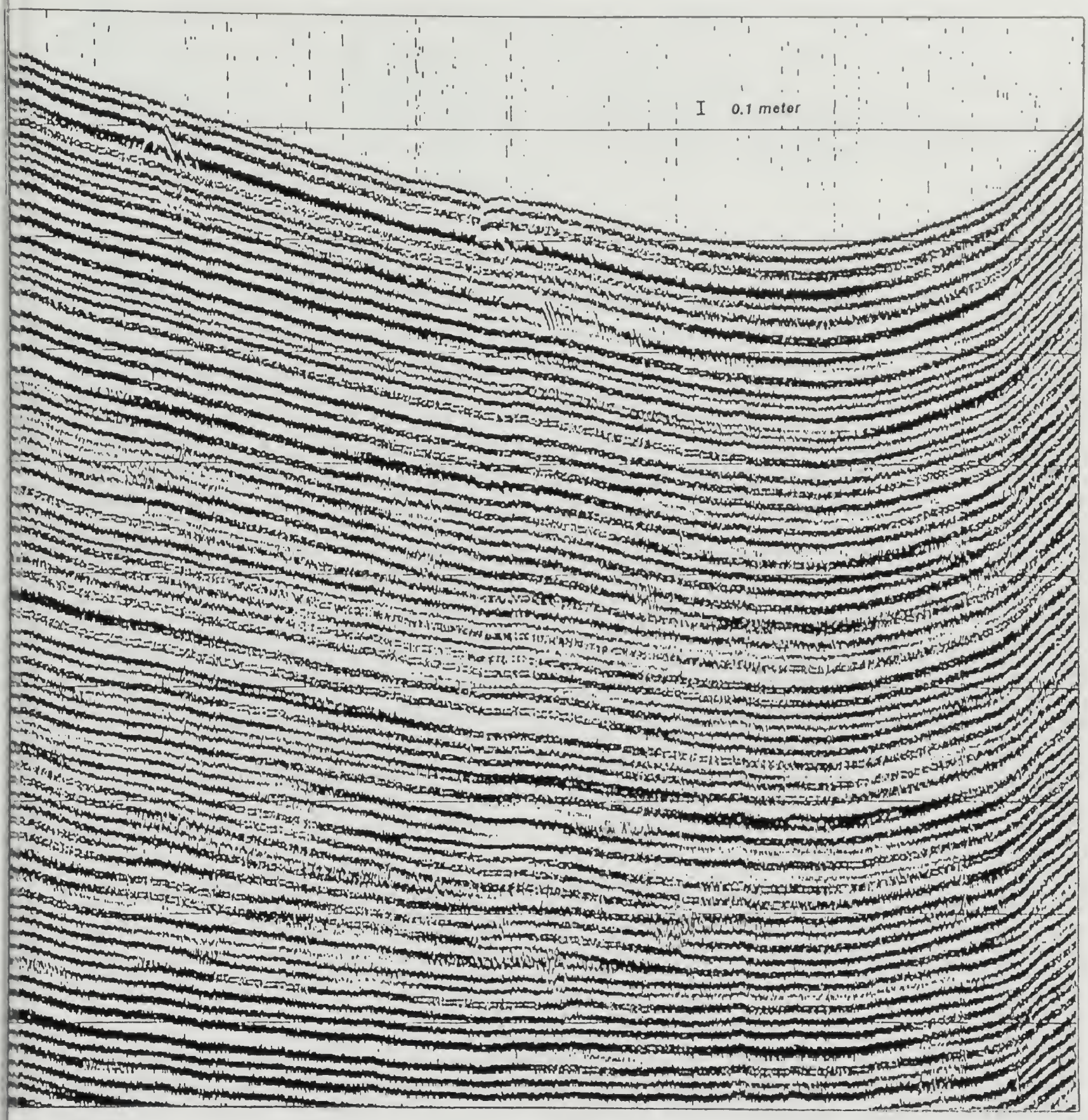


Figure 6d

Seismic profile. Expanded section of data.
Delay: 290 mSec. Sweep 12 mSec.

Figure 7

25m Interval Contour Map Produced by Britsurvey Post-Processing

- Deepest point found during 1991 survey (226.96 m).

o Deepest point found during 1903 survey (230.00 m).

A particular feature was investigated, on the suggestion of Mr. George Edwards (pers. comm.), that an area of increased depth lay at the base of the 'wall' off Urquhart Bay. The presence of a gully approximately 3.0 m deep was confirmed. Subsequent coring by the Loch Ness and Morar Project suggests that this may have resulted from turbidity currents caused by a major flood (Miller, 1993; Bennett, 1993; Bennett and Shine, 1993).

The seismic data are of considerable interest and show deep strata, thus confirming the need for equipment capable of extracting cores in excess of 10 m in length. The maximum depth of the loch was of particular interest, because of previous claims in excess of the depth originally charted by Murray and Pullar.

The 1991 survey found that the maximum depth lies in the North Basin, at a depth of 745 feet (226.96 m) at 413640E 6353598N U.T.M. (Note 4) or Latitude 57° 18' 57.1" N and Longitude 04° 26' 0l.6" W. This depth is a little less than the Murray and Pullar maximum of 754 feet (230 m) and was recorded 1.0 km further N.E. at a position approximately 1.0 km south of Urquhart Castle (Figure 7).

The maximum depth found in the South Basin was 726 feet (221 m), at 407538E 6345533N (U.T.M.) or Latitude 57° 14' 32.0" N and Longitude 0.4° 31' 55.3" W. Again, this is a little less than Murray and Pullar's figure of 739 feet (225 m).

Summary

In December 1991 the Loch Ness and Morar Project, in collaboration with Bentech Subsea, Marconi Udi, and Britsurvey, carried out a hydrographic survey of Loch Ness to map the contours, in particular those of the two deep-water North and South Basins, and to carry out seismic profiles.

The survey combined the use of a Bentech TOPAS topographic mapping and swathe profiling parametric sonar system, the Marconi Udi STARTRAK differential G.P.S. navigational system, and the post-processing and map production capabilities of Britsurvey.

Useful seismic data was collected and the maximum depth found was 745 feet (226.96 m), which is comparable to that found by Sir John Murray and Laurence Pullar's bathymetric survey of 1903.

Acknowledgements

Contributions to this paper were made by a number of colleagues and associates. In particular, the authors would like to thank Mr. John Minshull and members of the Loch Ness and Morar Project, Mr. Ian Padgham and Mr. David Whitcombe of Marconi Udi, Mr. Andrew Grey of Oceanscan, Mr. John Dybedal of Bentech Subsea, Mr. Keith Burgess of Svitzer Ltd, and Mr. David Siviter of Subtechnique who co-ordinated the operation.

The survey vessel was generously provided by Mr. Jim Hogan of Caley Cruisers, Inverness.

Special thanks are also due to Mr. and Mrs R.A. Bremner of the Official Loch Ness Exhibition Centre for their hospitality in accommodating the survey team.

Notes

1. The ROSETTA project (Recovery of Sediments Enabling Translations to Acoustics). The L.N.M.P.'s deep-coring programme is designed to complement the European Community REBECCA project (Reflection from Bottom, Echo Classification and Characterisation of Acoustic Propagation). This is a seismic programme for which the British participant is Dr. Bryan Woodward of Loughborough University of Technology.

2. Now Fugro Udi Ltd.

3. Now STARFIX II.

4. U.T.M. (Universal Terrain Measurement). International Spheroid (ED50) U.T.M. Projection, Zone 30, Central Meridian 3° W.

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Received July 1993

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RESULTS OF A WATER CHEMISTRY STUDY OF LOCH NESS

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Introduction

In May 1992 students from the University of Wolverhampton carried out water sampling and chemical analysis at Loch Ness, to consider the logistics and possible value of such a study.

Loch Ness presents considerable logistic problems because of the size and nature of the loch and the catchment. Maitland (1981) divided the catchment into four sub-catchments, based on the major drainage basins (see Figure 1). These sub-catchments can themselves be considered as diverse, because of the climatic domains, regional geology and land classification they span.

This short paper presents the results of the chemical analysis of the water samples taken. A useful statistical method is suggested to establish a sampling strategy which could be representative of all the inputs to Loch Ness.

Sample Collection

Samples were collected from all the input streams, the output (River Ness) and both the North and South Basins of the loch, and the sampling sites are detailed in Figure 2. Glass bottles were used to collect the samples, which were stored in a domestic refrigerator prior to transport to Wolverhampton for analysis by Induction Coupled Plasma. A broad scan programme was used for the elements shown in Table 1: sodium (Na), magnesium (Mg), iron (Fe), calcium (Ca), manganese (Mn), zinc (Zn), nickel (Ni), copper (Cu) and phosphorus (P).

Results

The detailed results presented in Table 1 consist of nine variables on samples ultimately obtained from 82 sites; at site numbers 16, 19, 20 and 28 the stream-beds were dry at the time for collection, and although numbers 68 to 84 were allocated in advance, no suitable sites for these were actually found.

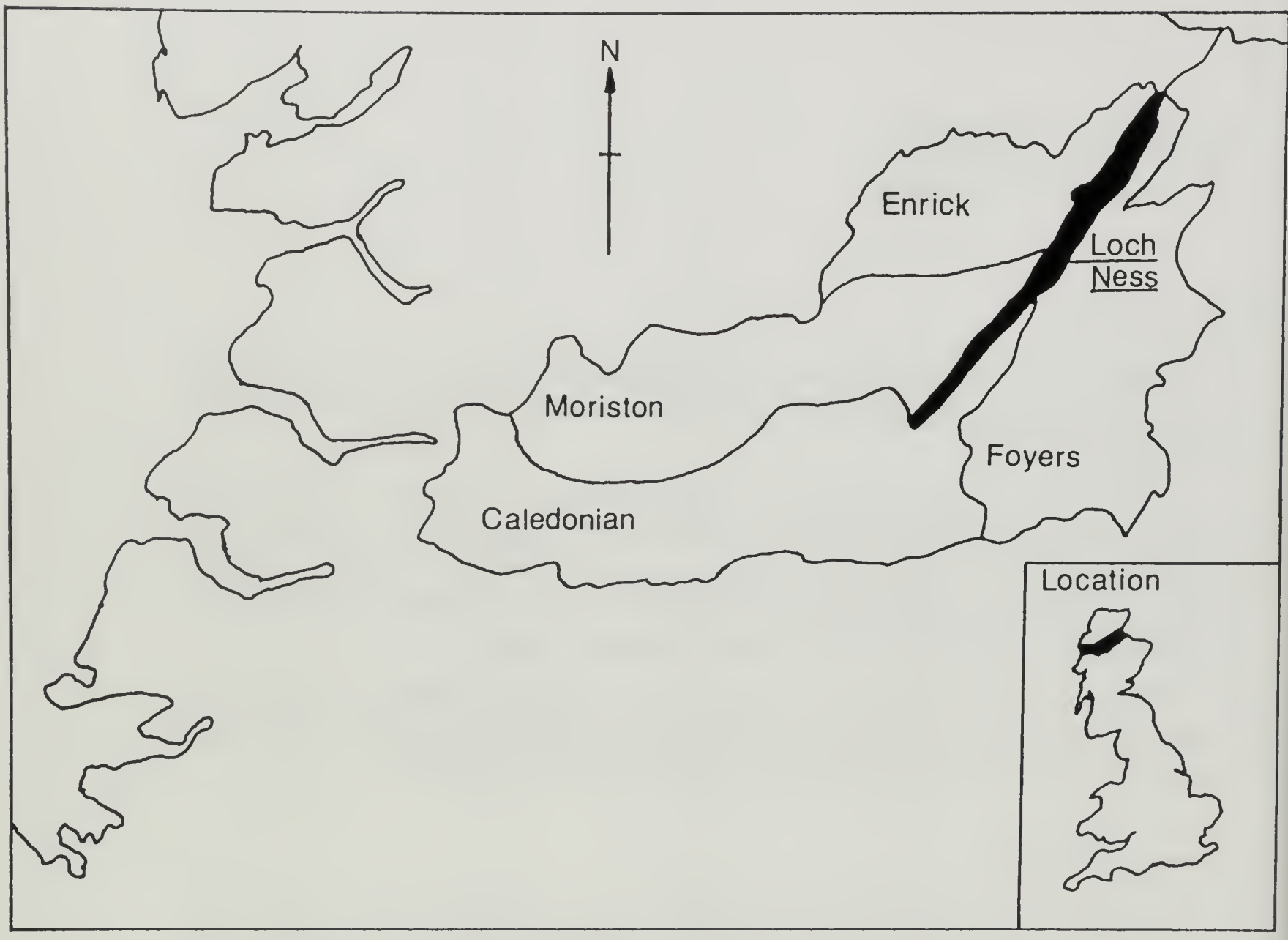

Figure 1

Loch Ness Catchment
(After Maitland, 1981)

Loch Ness sample sites

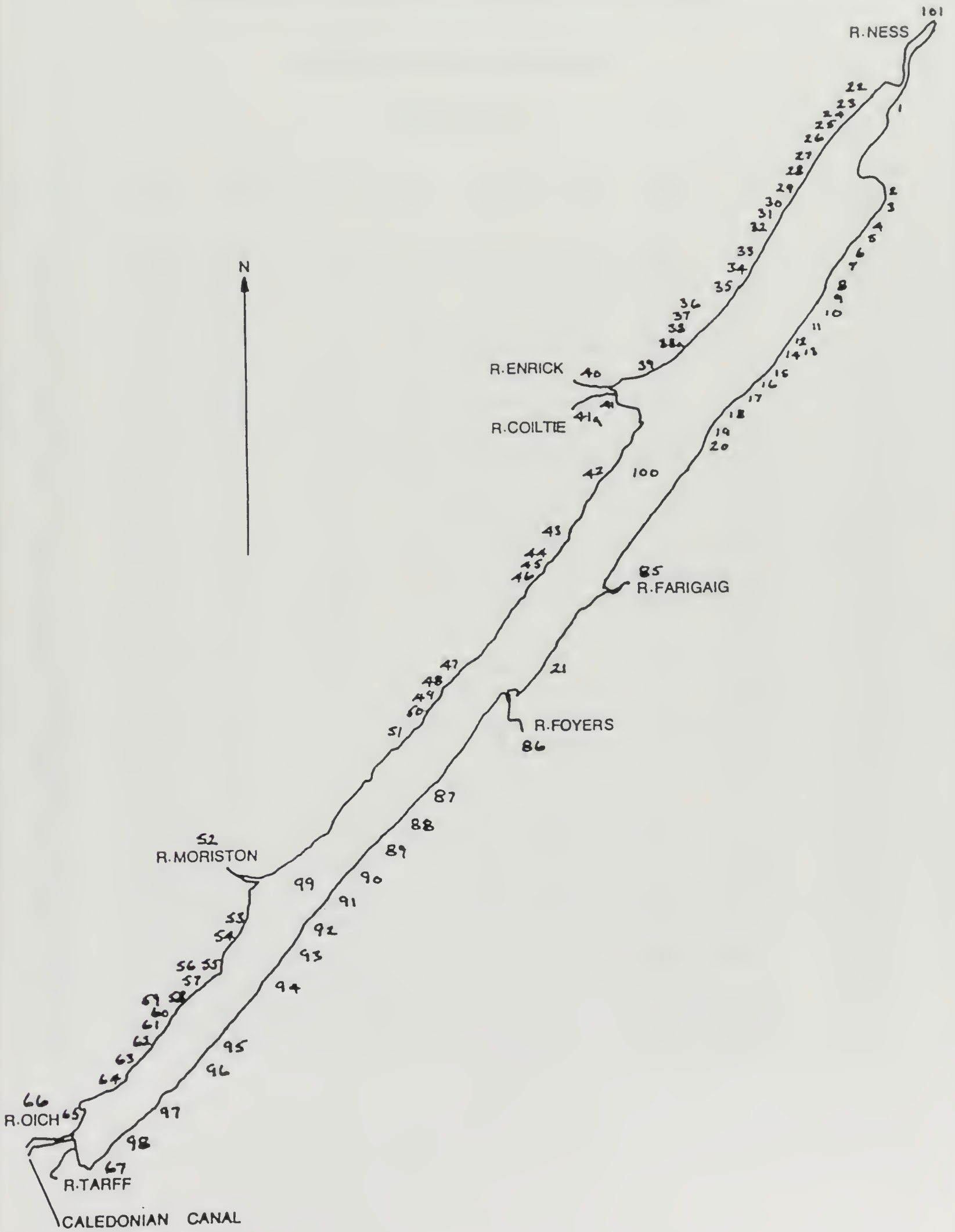

Figure 2

Table 1

The Water Chemistry of Loch Ness, May 1992

Elements in parts per million

T = Trace

Site	Na	Mg	Fe	Ca	Mn	Zn	Ni	Cu	P
1	2.59	3.29	0.03	40.62	0.01	T	0.01	0.02	0.02
2	2.70	2.44	0.05	19.02	0.01	0.02	0.02	0.04	0.02
3	4.28	2.74	0.06	18.27	0.01	0.03	0.03	0.07	0.08
4	4.65	2.80	0.05	21.49	0.01	0.01	0.03	0.04	0.04
5	6.51	4.28	0.05	37.34	0.01	0.01	0.04	0.04	0.07
6	3.34	5.22	0.07	48.92	0.01	0.03	0.04	0.06	0.06
7	3.18	2.25	0.05	16.80	0.01	0.03	0.04	0.06	0.06
8	2.32	4.49	0.07	30.08	T	0.03	0.04	0.08	0.07
9	2.48	6.16	0.07	40.85	0.01	0.03	0.05	0.08	0.07
10	2.23	4.79	0.09	29.86	T	0.04	0.10	0.12	0.13
11	3.32	4.52	0.07	36.34	0.01	T	0.04	0.10	0.08
12	2.30	1.56	0.05	13.03	0.01	0.01	0.05	0.06	0.06
13	1.82	1.60	0.07	13.62	T	0.03	0.04	0.06	0.12
14	7.48	1.52	0.05	10.26	T	0.02	0.07	0.05	1.11
15	1.61	1.87	0.07	17.45	T	0.03	0.08	0.11	0.09
17	6.95	2.36	0.10	7.28	0.03	0.02	0.02	0.18	0.14
18	2.48	1.91	0.11	5.82	0.03	0.02	0.01	0.25	0.20
21	4.12	2.79	0.08	9.36	0.03	0.02	0.05	0.21	0.20
22	7.83	2.22	0.11	4.31	0.01	0.03	0.02	0.19	0.23
23	1.90	1.63	0.11	5.98	0.03	0.03	0.01	0.23	0.21
24	2.07	1.65	0.12	5.26	0.01	0.03	T	0.21	0.24
25	2.42	1.77	0.12	10.27	T	0.02	0.04	0.23	0.22
26	1.79	1.05	0.12	3.59	0.01	0.03	0.02	0.21	0.19
27	1.10	0.90	0.13	3.38	T	0.03	0.02	0.23	0.23
29	8.06	8.64	0.13	14.91	T	0.04	0.05	0.27	0.24
30	3.33	3.00	0.09	5.42	T	0.04	0.07	0.31	0.29
31	2.83	2.44	0.14	7.24	0.01	0.04	0.05	0.27	0.29
32	7.81	4.24	0.15	6.72	0.02	0.04	0.07	0.29	0.25

Table 1

The Water Chemistry of Loch Ness, May 1992

Elements in parts per million

T = Trace

Site	Na	Mg	Fe	Ca	Mn	Zn	Ni	Cu	P
33	1.58	2.31	0.05	7.63	0.04	0.04	0.07	0.30	0.27
34	4.48	1.98	0.14	5.77	0.04	0.03	0.08	0.30	0.01
35	1.56	3.45	0.15	10.45	0.01	0.04	0.12	0.31	0.29
36	2.52	2.16	0.06	19.82	0.07	0.05	0.02	0.11	0.01
37	2.70	1.34	0.03	5.60	0.01	0.01	0.01	0.06	0.09
38	8.40	2.75	0.04	6.27	0.02	0.01	T	0.13	0.03
38a	2.88	1.49	0.04	6.80	0.02	0.01	0.02	0.12	0.12
39	2.98	3.08	0.02	10.32	T	0.02	T	0.09	0.12
40	5.23	3.66	0.04	15.14	0.03	0.01	0.02	0.12	0.10
41	2.42	1.23	T	4.64	0.02	0.02	T	0.08	0.06
41a	3.84	2.56	0.03	10.00	0.01	0.01	0.02	0.08	0.08
42	2.93	3.17	0.02	13.62	0.02	0.01	0.02	0.06	0.06
43	3.38	5.28	0.05	19.55	0.02	0.02	T	0.09	0.12
44	3.35	1.99	0.39	6.66	0.02	0.01	0.01	0.04	0.07
45	3.73	4.92	0.02	16.72	0.03	0.01	T	0.09	0.10
46	3.27	2.83	0.01	9.49	0.03	0.01	T	0.09	0.10
47	5.03	6.26	0.05	11.95	0.03	0.01	0.01	0.10	0.09
48	1.84	1.50	0.01	4.54	0.04	0.02	T	0.09	0.10
49	5.63	4.23	0.05	13.03	0.03	0.01	T	0.11	0.12
50	2.83	2.47	0.05	12.77	0.02	0.02	0.01	0.11	0.12
51	3.49	0.93	0.02	3.53	0.02	0.01	T	0.13	0.12
52	1.75	0.62	0.03	1.93	0.04	0.02	T	0.09	0.16
53	2.53	0.72	0.02	1.10	0.03	0.02	0.01	0.12	0.02
54	1.93	0.76	0.04	1.72	0.04	0.02	0.01	0.10	0.11
55	5.88	1.40	0.06	2.07	0.01	0.01	0.04	0.11	0.06
56	2.16	0.40	0.01	1.69	0.03	0.02	0.01	0.11	0.11
57	6.64	1.85	0.01	0.85	0.03	T	0.07	0.03	0.05
58	1.01	0.47	0.02	1.60	0.02	T	0.07	0.03	0.04

Table 1

The Water Chemistry of Loch Ness, May 1992

Elements in parts per million

T = Trace

Site	Na	Mg	Fe	Ca	Mn	Zn	Ni	Cu	P
59	2.63	0.34	0.01	1.03	T	0.05	0.06	0.04	0.01
60	7.28	3.03	0.03	2.47	T	0.04	0.06	0.07	0.07
61	1.54	0.80	0.04	1.00	0.01	0.01	0.03	0.06	0.07
62	4.40	0.96	T	0.56	0.01	T	0.04	0.06	0.08
63	1.25	0.36	0.04	0.79	0.01	0.01	0.05	0.10	0.07
64	3.35	1.13	T	0.94	T	T	0.04	0.08	0.06
65	2.37	0.66	0.01	1.59	0.03	0.03	0.03	0.09	0.12
66	1.43	0.58	0.02	1.22	0.02	0.01	0.03	0.10	0.06
67	2.11	1.01	0.08	1.20	0.02	0.01	0.02	0.09	0.10
85	1.28	0.65	0.17	2.56	0.01	0.03	0.02	0.09	0.09
86	0.91	0.94	0.08	1.47	0.20	0.02	0.02	0.10	0.07
87	0.09	0.78	0.02	3.35	0.03	0.03	0.03	0.12	0.09
88	0.41	0.57	0.11	1.25	0.04	0.03	0.03	0.10	0.13
89	0.21	0.92	0.01	2.12	0.04	0.03	0.06	0.13	0.13
90	0.45	0.62	0.03	3.42	0.06	0.03	0.05	0.12	0.11
91	10.41	3.59	0.06	9.20	0.06	0.01	0.05	0.13	0.14
92	0.76	1.17	0.06	11.06	0.01	0.04	0.06	0.17	0.17
93	0.32	0.42	0.02	2.58	0.03	0.04	0.07	0.14	0.17
94	1.02	0.79	0.02	4.65	0.02	0.02	0.07	0.19	0.13
95	6.11	1.69	0.02	5.29	0.03	0.04	0.07	0.16	0.13
96	4.49	2.03	0.01	5.27	0.01	0.02	0.10	0.15	0.15
97	0.28	0.42	0.05	2.94	0.01	0.02	0.09	0.18	0.16
98	1.65	1.44	0.07	8.34	0.01	0.03	0.11	0.14	0.12
99	0.45	0.53	0.06	1.21	0.01	0.03	0.10	0.20	0.19
100	1.14	1.34	0.05	5.61	0.02	0.02	0.10	0.17	0.17
101	0.28	0.40	0.07	1.49	0.01	0.03	0.12	0.23	0.17

Analysis

In an attempt to elucidate this complex data set, simultaneous R-mode and Q-mode factor analysis was applied. R-mode and Q-mode factor analyses have previously been used in various studies to explore multivariate relationships within suitable data sets (Davies, 1986). R-mode factor analysis explores the relationship of the variables, while Q-mode factor analysis attempts to explore relationships between the samples. The methods are based on the calculation of eigenvectors which can be plotted on two-dimensional factor diagrams. The application of simultaneous R-mode and Q-mode factor analysis extracts a common set of factors of the variable and sample factor loadings, which are relative to the same set of factors. Variable and sample factor loadings can therefore be plotted in the same two-dimensional factor space.

A discussion of the mathematical procedure involved is given by Zhou, Chang and Davies (1983), and a worked example can be found in Walden (1990).

The results of the first application of simultaneous R-mode and Q-mode factor analysis are shown on Figures 3 and 4. These are identical factor space plots, but have been separated to give a clearer representation of the results. Figure 3 gives the variable loadings, and Figure 4 gives the sample loadings. The variance of the first two factors is 44.62%, which implies that the factor solution is not significantly reducing the dimensionality of the data set.

Figure 3 implies that certain elements show signs of correlation, eg. Na, Mg and Ca have negative factor 2 loadings. Figure 4 cannot be readily interpreted; it does, however, imply certain groupings of the samples.

In future it is proposed to divide the original data set into two groups of variables, based on the results in Figure 3, and to apply simultaneous R-mode and Q-mode factor analysis to the two data sub-sets.

The samples will also be divided into two groups, based on the results in Figure 4: (a) positive on factor 1 loadings, and (b) negative on factor 1 loadings. Using the original data, simultaneous R-mode and Q-mode factor analysis will also be applied to these two further data sub-sets.

The results presented here are not yet complete, because of the author's commitments elsewhere. It is believed, however, that the method proposed offers considerable potential for catchment-based studies of water chemistry. To study a catchment as large and diverse as Loch Ness requires considerable resources which

Figure 3

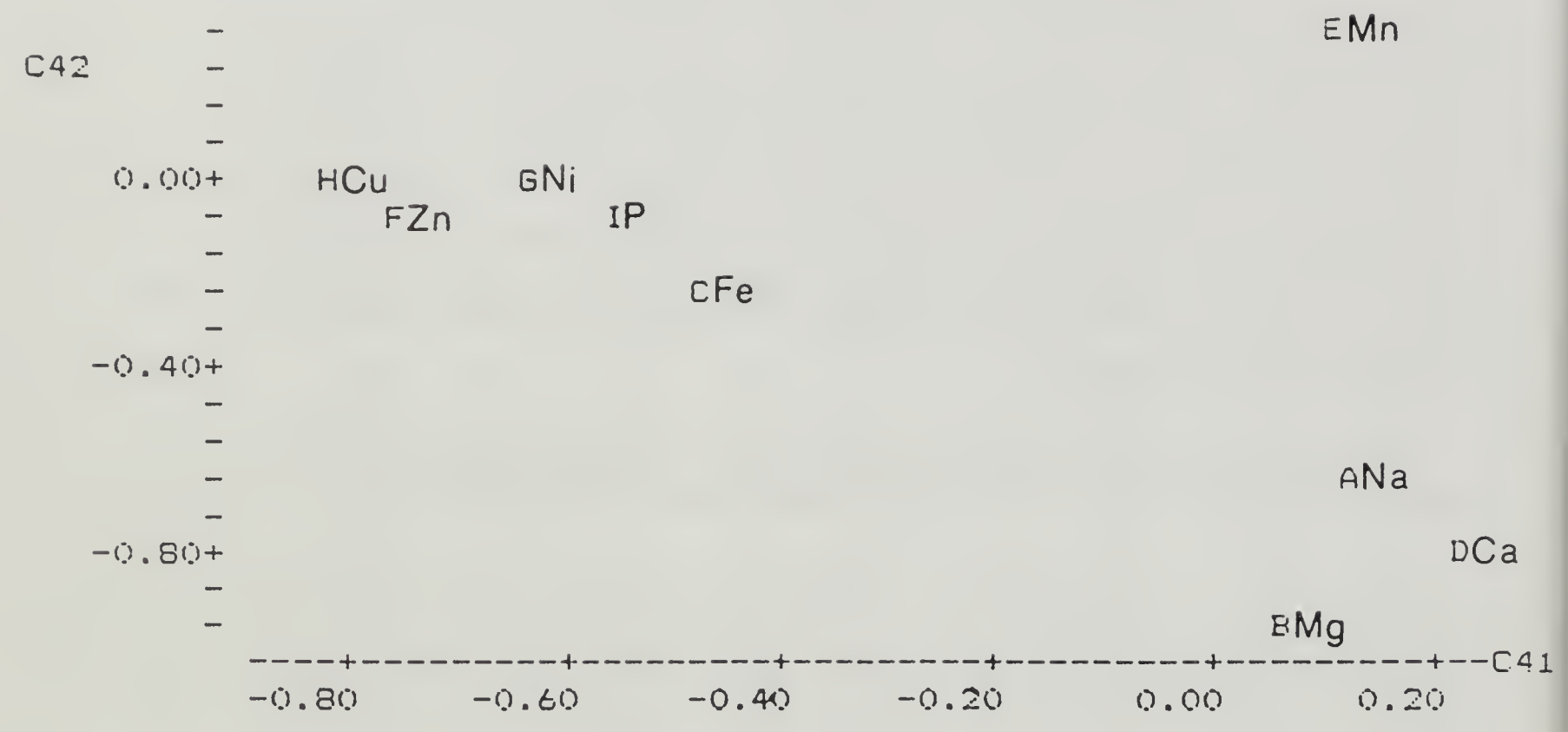

Figure 3

R-Mode and Q-Mode Factor Analysis

Variable Loadings

(See page 51)

Figure 4

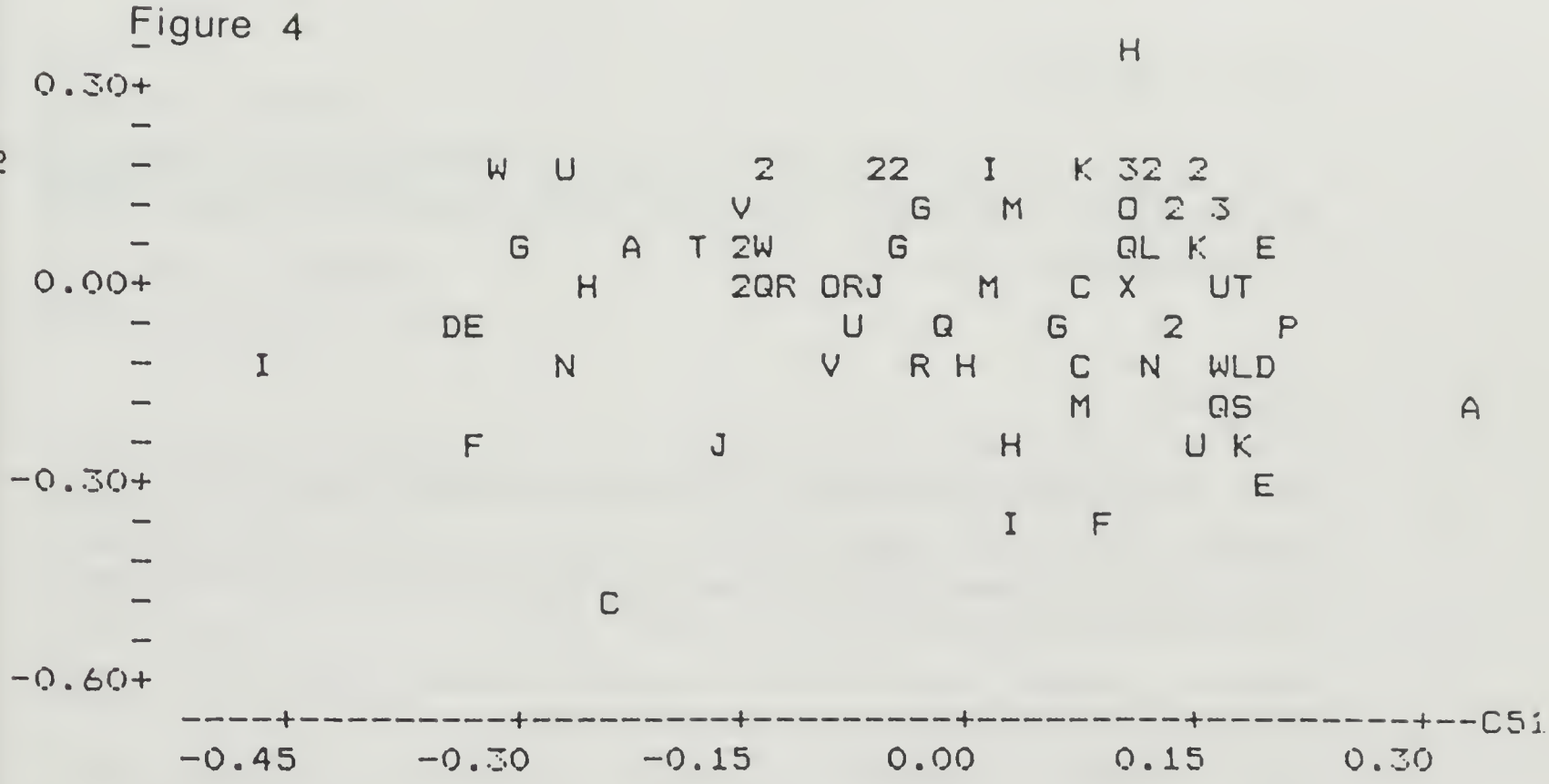

Figure 4

R-Mode and Q-Mode Factor Analysis

Sample Loadings

(See page 51)

may not be readily available. However, it is considered that an integrated desk-top study, such as Maitland (1981), and a one-off statistical analysis such as this, could develop a viable sampling strategy.

Acknowledgements

The author would like to thank his colleagues and students at the University of Wolverhampton for all the work undertaken, and the Loch Ness and Morar Project for making this study possible.

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Received May 1993

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REVIEW OF CURRENT WORK ON LOCH NESS SEDIMENT CORES

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The sediment mapping and coring programmes of the Loch Ness and Morar Project are now beginning to contribute to our understanding of Britain's greatest volume of fresh-water, so it is hoped that this short introductory review of sediment-coring work may make many aspects of its importance clear to the general reader.

Acidification of Lochs

To begin with, in Loch Ness it is very probably the sheer volume of water itself which has provided a buffer against acidification. Many small lochs, particularly to the south of the Great Glen, have become very acidified, some of them losing their fish populations altogether. Many of these lochs are at present being studied by a team lead by Professor R. Battarbee of the Environmental Change Research Centre at University College London (U.C.L.).

It is now well established that a significant cause of acidification is atmospheric contamination, and an indication of the degree to which a lake is subject to sulphur pollution is given by the numbers of microscopic 'carbonaceous particles' falling into it. These spherical particles result from the burning of fossil fuels, especially oil, and have increased dramatically in sediments from about 1940, when this form of energy became increasingly used for power generation.

Loch Ness cores, taken in 1990 by the Loch Ness and Morar Project (L.N.M.P.) and analysed by Dr. Neil Rose at U.C.L. (pers. comm.) (Note 1), show typical concentrations of these particles, beginning between 1850 and 1870, increasing rapidly between 1949 and 1960, and reaching a peak in the 1970s.

Diatom Record

The diatom record, as studied by Dr. Vivienne Jones of the U.C.L. team, permits reconstruction of pH. Despite the sulphur contamination, acidity has remained relatively constant over the years since 1850, and agrees well with the current pH of 6.5 (Dr. Vivienne Jones, pers. comm.) (Note 1). The silica frustules of diatoms remain intact within the sediments, and can be identified. Since the requirements of many species are known with regard to temperature, nutrient richness, and pH, it is possible to reconstruct a quite detailed picture of conditions within the loch over this time.

Eutrophication

One of today's other great concerns is about the eutrophication of lakes. Again the diatom record is the main indicator of change. Until about 1970 the diatom community was dominated by benthic forms, presumably washed in from the shores and by rivers. From then on, however, there is a dramatic increase of planktonic species, such as *Aulacoseira subarctica* and *Asterionella formosa* (Dr. Vivienne Jones, pers. comm.) (Note 1). This situation is typical of the first impact of eutrophication in lakes throughout the world, even though studies of the loch's chemistry still show, for example, extremely low levels of phosphorus (Jenkins, 1993). Thus, despite its great volume, Loch Ness is not entirely immune from change induced by man's activities within its catchment.

Pollen

Pollen grains from the loch catchment's vegetation also endure for thousands of years, locked in the sediments. Dr. Sylvia Peglar, at the University of Bergen, has prepared pollen diagrams from cores taken by the Loch Ness and Morar Project, and these show events over the last three thousand years as tree pollens gradually give way to herbs and the cereals increase. Finally the tree pollens increase again in the recent past, as new species of conifer were established in plantations (Dr. Sylvia Peglar, pers. comm.).

Isotopes

Although pollen is one example where historical sequences are well enough understood to provide a dating framework for the cores recovered, for recent events a higher resolution method is available to reveal the rate of sedimentation, and thus to date events within the core. The method used by U.C.L. is based upon

the relatively rapid decay (22.26 years half-life) of the naturally occurring radio-isotope ^{210}Pb, and has dated Loch Ness cores back to 1830, thus covering almost all of the changes brought about by industrialisation.

The chronology can also be checked by the presence of the rather less natural caesium isotopes, such as ^{134}Cs and ^{137}Cs. Thus the 1963 peak in nuclear bomb fall-out from atmospheric testing is faithfully recorded in the sediment at 9.0 cm down. From the 3.0 cm mark on the graph, there points the long dark accusing finger of Chernobyl (Dr. P.G. Appleby, pers. comm.) (Note 1).

PCBs and PAHs

Other undesirable compounds, such as PCBs, PAHs and trace metals, are being studied by the Newcastle Research Group in Fossil Fuels and Environmental Geochemistry. Mansfield (1992) and Bracewell (1993) show that the increase in these compounds peaks at about 1960. The persistent pesticide DDT is still detectable in the upper sediments. In the uppermost sediments there is evidence of some oil pollutants, probably derived from fuels used by vessels on the Caledonian Canal. The work of Mansfield and Bracewell on the lipids shows that the bulk of the sediments are derived from terrestrial vegetation, rather than from productivity within the loch. As will be seen, the catchment has great influence upon the loch's biology (see Sanders, Jones and Shine, 1993).

Sediment Character

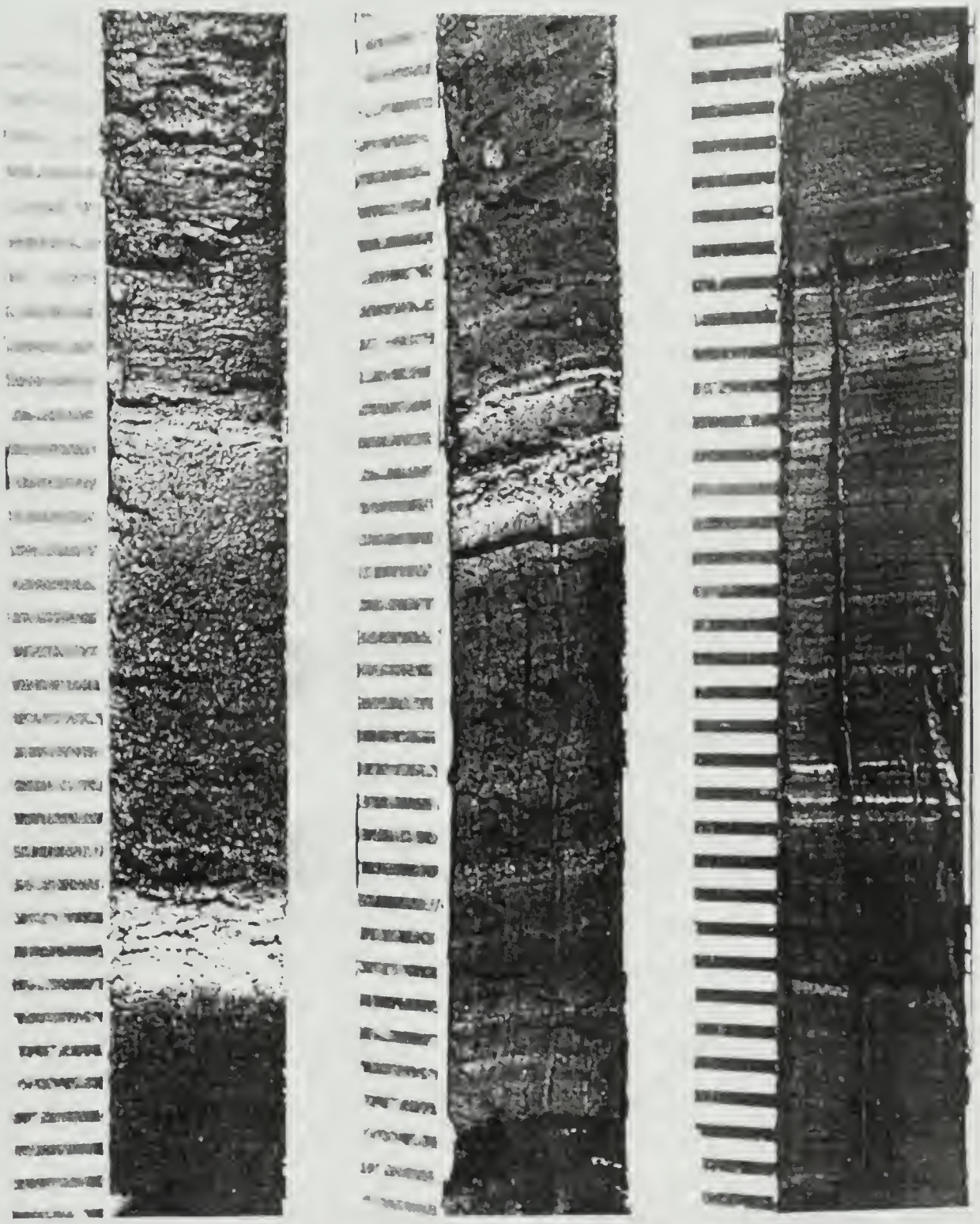
The differing features of the loch's catchment have considerable influences upon the character of the sediments. There is a pronounced rainfall gradient across the Highlands from west to east, which means that the bulk of the water enters the loch from the south-west end. It seems that this brings with it the majority of the organic material derived from terrestrial vegetation, particularly peat and leaves. Bennett (1993) has produced a sediment map prepared from the L.N.M.P.'s 'Short-Core' programme (Figure 1). This clearly shows that each inlet contributes different characteristics to the sequences of sediment build-up. Thus it has been confirmed that the rise in the bed opposite Foyers is composed of coarse mica sand brought down by the river, and the same is true off Invermoriston, although there is a much greater percentage of vegetable detritus there. Clays are exposed at shallow sediment depth at the loch's northern end towards Dores. Overall, sediments are focused towards the deeper water, where the contemporary rate of sedimentation exceeds 1.0 cm per year in the North Basin.

Figure 1

A. The South Basin sediments show an influx of coarse material near to the side 'wall'.

B. Further from the side slopes, the influx of material (the event marker), thought to result from a flood in 1868, is thinner, with less sand below the clay capping.

C. The finely laminated sediments of the North Basin, away from the river inputs. The event marker (at the top) is almost entirely clay.



A B C

Figure 1

Disturbance by the Great Flood

One feature of particular interest, discovered in 1990, was a disturbance in the rate of sedimentation, represented by a distinctive light grey clay layer, initially observed at 30-50 cm sediment depth throughout the dark brown organic deposits of the North Basin. The ^{210}Pb dating clearly suggests a major event in the latter part of the nineteenth century.

This feature was widespread within the loch, thus providing a clue to its origin. In cores from the South Basin, instead of the characteristic thick clay layer, the same event appeared to be represented by much coarser material and layers of intact terrestrial vegetation. This strongly suggests a major flood.

Throughout the summer of 1992 the layer was traced along and across the loch, and, in the North Basin, was tracked to the mouth of Urquhart Bay. A transect of three cores showed the clay layer to be thickest nearest to the Bay, capping no less than 50 cm of coarse sand, before resumption of the normal pattern of deposition. The sand layer tapered away with distance from the Bay, and the clay thinned to the north and south. The transect results were quantified by particle size analysis by Miller (1993), who points to the great flood of 1868 (Anon., 1868; Barron, 1985) as the most likely cause of this huge outwashing of material.

On closer study of 27 short cores, Bennett (1993) noted the disturbance in sedimentation to be more complex than was initially observed. In the deeper parts of the North Basin the grey clay layer overlies a fining upwards section of dark brown silts. Bennett suggests that a turbidity current, triggered by the flood, plunged down the slopes of Urquhart Bay towards the deep North Basin. The L.N.M.P.'s hydrographic surveys show two sub-lacustrine channels down the north wall at this point (Shine and Martin, 1988), and the current could have cut the small gully into the base of the 'wall' 200 m down (Young and Shine, 1993).

In the narrower South Basin, Bennett discovered that the coarser particles and vegetation were only part of a thicker sequence of material, each capped by a much thinner, but clear, light clay layer. Here, similar powerful erosive currents, under the extraordinary conditions of the great flood of 1868, originated not only from rivers but also extended right across the loch bed from the Horseshoe Scree. The particles of sand were deposited first, then the silts, twigs and vegetable matter, and finally, perhaps months later, the last of the fine clay particles settled to blanket the basin floors.

Sediment Lamination

This spectacular event may well provide the key to the most interesting of the discoveries in the Loch Ness sediments, i.e. that they are laminated. The >200 m depth of the loch provides an exceptionally stable resting place for silts and clays, which in shallower environments would be disturbed and resuspended. Thus, characteristic light/dark 'couplets' are preserved. The predominantly allochthonous origin of the sediment suggests the possibility that the laminae are precipitation controlled annual features; however, this has not been proved. One Ph.D. thesis, funded by the University of Wolverhampton, has now been devoted to determining the nature and composition of the Loch Ness laminations. The L.N.M.P.'s 'Project Hour-Glass' has been set up on the loch bed, to remain in place for a whole year, in order to aid this research. The principle is to concentrate the sediment into a narrow tube, in order to emphasise any differences in the sediment's monthly character.

The quality of laminations establishes Loch Ness as a premier site for the study of climate change in Great Britain. Once the basic language of the laminations is understood, each divided core will reveal a catalogue of information about the history of Loch Ness. That history begins with glacial clays deposited by retreating ice some 12,000 years ago. The 'Rosetta' project (L.N.M.P.'s 'Long-Core' programme; Note 2) is steadily being driven towards those clays. Amongst other things, this will recover pollen and mineral records which will bear witness to such events as the general re-advance of the ice (often termed the 'Loch Lomond stadial'; see Sissons, 1979) to post-glacial bursts of productivity within the loch and its catchment, and to man's arrival in the Great Glen.

Relationships

The northerly location of Loch Ness makes it possible to relate tephras (microscopic glass shards), enclosed within the sediments, to Icelandic volcanic eruptions. The first depopulation of the Highlands, during the Bronze Age, was coincidental with one resultant 'volcanic winter', and potential relationships are being studied by Dr. Andrew Dugmore, of the Department of Geography at the University of Edinburgh. On another topic, it may be possible, by looking for marine species of diatoms, to resolve the question of whether or not the sea entered Loch Ness, prior to isostatic and eustatic readjustments to the loch's present position of 15.8 m above sea level. The cataclysmic release of water, from vanished ice-dammed lakes far up the Great Glen, proposed by Sissons (1979) to have been forced northwards through Loch Ness in a period of only 48 hours, should also be represented in the deep loch floor deposits.

Radar pictures taken through the Antarctic ice cap have revealed water on the bedrock. This offers the possibility that the very deep basin of Loch Ness may not have been completely scoured by ice. It is therefore possible, if only marginally, that pockets of interglacial sediments lie preserved, and might be penetrated to reveal an even earlier history than has thus far been considered.

Conclusion

In conclusion, Loch Ness should not be seen as some untouched and pristine cul-de-sac. It is very far from that; it is an open-ended time capsule, packed with the footnotes to very broad events, including the coming of man to the Great Glen and his activities here and further afield. Sedimentary records have proved to be a remorseless treatise in cause and effect, and give dramatic confirmation of man's power to change his environment.

Notes

1. V. Jones and N. Rose (Environmental Change Research Centre, University College London) and P.G. Appleby (University of Liverpool): The Recent History of Loch Ness. Poster paper: displayed at British Ecological Society's winter meeting and A.G.M., University of Lancaster, 15th-17th December 1992; and at Scottish Freshwater Group's 50th Meeting, University of Stirling, 2nd-3rd February 1993.

2. The ROSETTA project (Recovery of Sediments Enabling Translations to Acoustics). The 'Long-Core' programme is designed to complement the European Community REBECCA project (Reflection from Bottom, Echo Classification and Characterisation of Acoustic Propagation). This is a seismic programme for which the British participant is Dr. Bryan Woodward of Loughborough University of Technology.

Acknowledgements

The authors would like to express their best thanks to all the L.N.M.P. sediment collaborators, and in particular to Mr. Alan Pike for his assistance with the pioneer coring work and for his subsequent technical advice and encouragement.

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Received June 1993

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LOCH NESS SEDIMENTS: A PRELIMINARY REPORT

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Introduction

The sediments of Loch Ness have received little attention in the past from palaeolimnologists. Pennington, Haworth, Bonny and Lishman (1972) reported mainly grey microlaminated glacial clay in a core taken from a depth of 50 metres off Dores. This may explain why further research on the sediments has been somewhat neglected until quite recently.

Loch Ness is some 230 metres deep, and it is therefore difficult to remove sediment cores from the bottom of the loch with the equipment readily available to palaeolimnologists. The Loch Ness and Morar Project, however, has recently developed a technique capable of collecting cores from a depth of 220 metres. Cores from this depth have been examined by members of the Loch Ness Sediment Group. The sediments are rich in organic material and laminated to a depth of 2.0 metres.

This paper presents some of the preliminary bulk geochemical and mineral magnetic results from a 1.2 m core, collected in 1990 from a depth of 170 m in the North Basin (National Grid reference NH 572326).

The research being undertaken is set within the lake watershed ecosystem model, which has proved to be a useful tool in developing a spatially integrated understanding of lake and catchment processes.

Bormann and Likens (1969) identified the framework of this model by monitoring nutrient cycles within a catchment, and relating their results to climatic change and human activity in the catchment. This concept was further developed by Oldfield (1977) to consider the sediment as a record of past environmental conditions within the lake and its catchment. The sediments are analysed for variations in their physical, chemical and organic properties, which are then interpreted within the lake watershed ecosystem model framework.

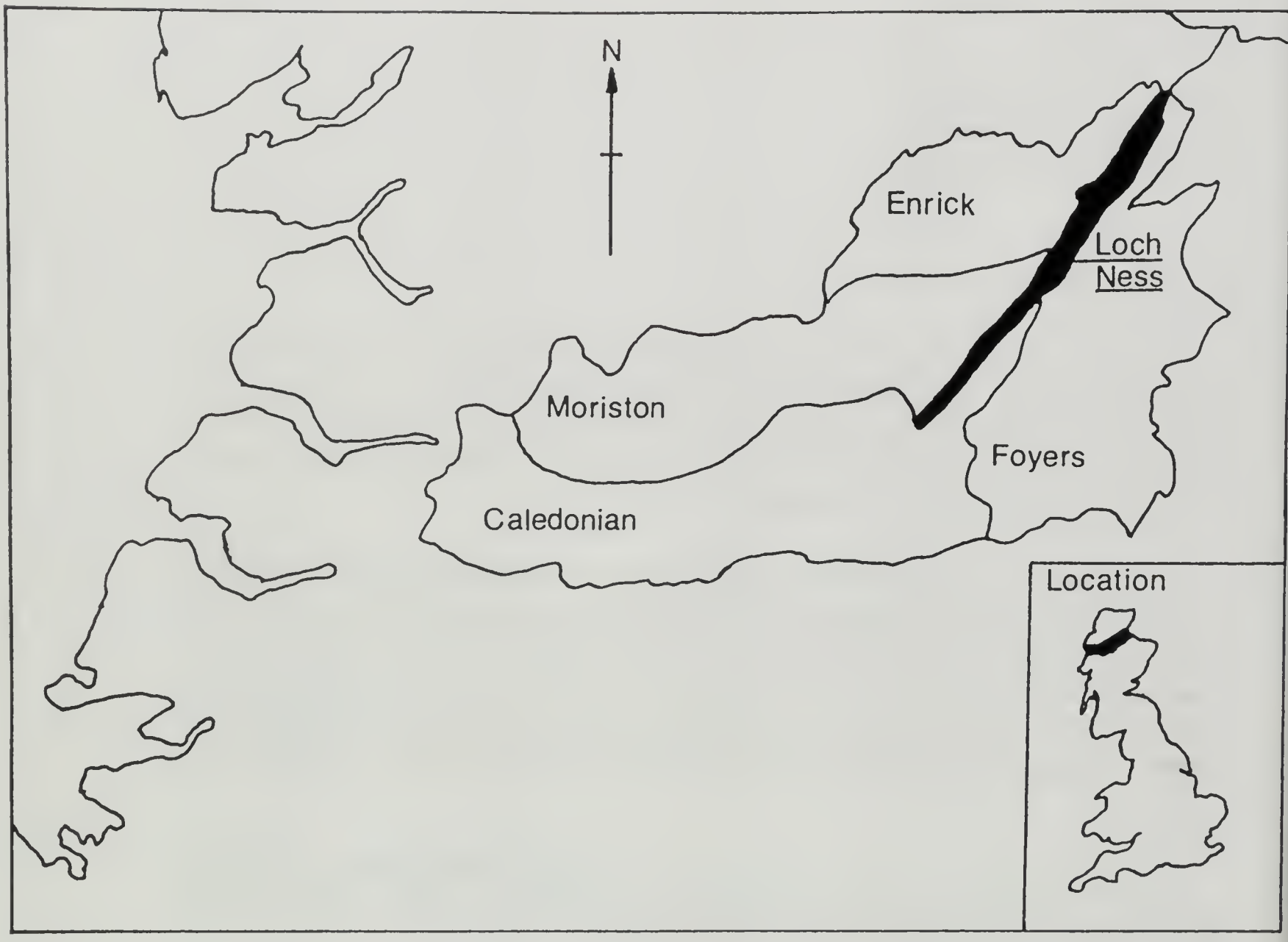


Figure 1

Loch Ness Catchment
(After Maitland, 1981)

The sediment can be considered as a diverse matrix of inorganic and organic materials, derived from the catchment (allogenic), from within the lake (authigenic), and within the sediment (diagenic). To distinguish between these sources presents any one discipline with considerable problems, which can only be overcome by multi-disciplinary studies (Haworth and Lund, 1984).

Mineral magnetic studies examine the physico-chemical changes of the iron compounds brought about by changes in the environment. Thompson and Oldfield (1986) present various examples of mineral magnetic studies, and Oldfield (1991) presents a recent review of the research being carried out in this discipline. The advantage of this form of analysis is its speed and non-destructive method, which allows further methods of analysis to be carried out. A brief interpretation of the magnetic parameters measured is presented in Table 1.

Geochemical studies elucidate the environmental processes which control the distribution of inorganic elements within the sediment. Mackereth (1966) established methods of interpretation which have been further developed, and questioned, by other workers in this field, e.g. Engstrom (1983).

Site Description

Loch Ness is situated in the Highland Region of Scotland , and is one of several lochs, linked by the Caledonian Canal, which follow the Great Glen fault (Figure 1). Loch Ness is the largest body of natural freshwater, and has the greatest mean depth of any lake, in Great Britain. The catchment of the loch spans almost the entire width of the Scottish mainland, and incorporates a variety of climatic domains. The geology of the catchment exposure consists of a complex suite of metamorphic, intrusive igneous and old red sandstone rocks with post-Devensian deposits (Craig, 1991). Land classification of the catchment is predominantly mountain moorland or rough pasture, with crop and grass land only a minor proportion in the glens.

The main industries are agriculture and tourism. Sheep farming and forestry dominate the upland areas, with minor livestock and arable farming in the crofting areas of the glens. Hydro-electric schemes and various cottage industries are common in the region. Aluminium smelting was carried out on the shore of Loch Ness at Foyers from 1895 to 1967.

The morphometry of the loch and its catchment is presented in Table 2. Hydrological and land use data are given in Table 3, which follows Maitland's (1981) method of catchment subdivision.

Table 1

Mineral Magnetic parameters

(Walden, 1990)

Magnetic mass specific susceptibility:

The ratio of magnetisation induced, to the intensity of a small applied magnetic field (no remanence is induced, so the sample retains its original magnetic properties). It can be considered as being roughly proportional to the concentration of ferrimagnetic minerals within the sample.

Frequency dependent susceptibility:

The variation of susceptibility with respect to the frequency of the applied field. Viscous magnetic grains within the stable single domain/superparamagnetic boundary show a delayed response to the applied field.

Anhysteretic remanent magnetisation:

The remanence induced in the sample by the applied field tends to be retained by ferrimagnetic stable single domain size grains.

Saturation isothermal remanent magnetisation:

The maximum amount of magnetic remanence which can be imparted to a sample by a large applied field. (With the fields used, not all magnetic minerals will have been saturated). This parameter relates to mineral type and concentration.

Table 2

LOCH NESS MORPHOMETRY

(After Maitland, 1981)

Feature	**Dimensions**
Length (km)	39.00
Mean width (km)	1.45
Surface area (km^2)	57.00
Catchment area (km^2)	1727.00
Maximum depth (m)	230.00
Mean depth (m)	132.00
Altitude, O.D. (m)	15.80

Table 3

Hydrological and Land Use data, Loch Ness Catchment
(After Maitland, 1981)

Loch Ness sub-catchments

	Caledonian	**Moriston**	**Foyers**	**Enrick**	Total
Area(km^2)	634.0	512.0	404.0	177.0	1727.0
Land Use(km^2)					
Rough	479.3	418.7	323.1	132.9	1354.0
Water	41.9	22.5	8.5	3.3	76.2
Arable	0.1	2.5	17.7	12.3	32.6
Urban	3.6	1.7	1.4	0.8	7.5
Forest	103.8	64.7	53.2	26.2	247.9
Other	5.3	2.3	0.5	1.9	10.0
Lochs	67.0	108.0	93.0	87.0	355.0
Stream Junctions	1047.0	542.0	342.0	116.0	2047.0
Waterfalls	28.0	10.0	5.0	1.0	44.0
Houses	131.0	245.0	359.0	299.0	1034.0
Metalled Road (km)	82.0	106.0	116.0	64.0	368.0

FIGURE 2. MASS SPECIFIC SUSCEPTIBILITY.

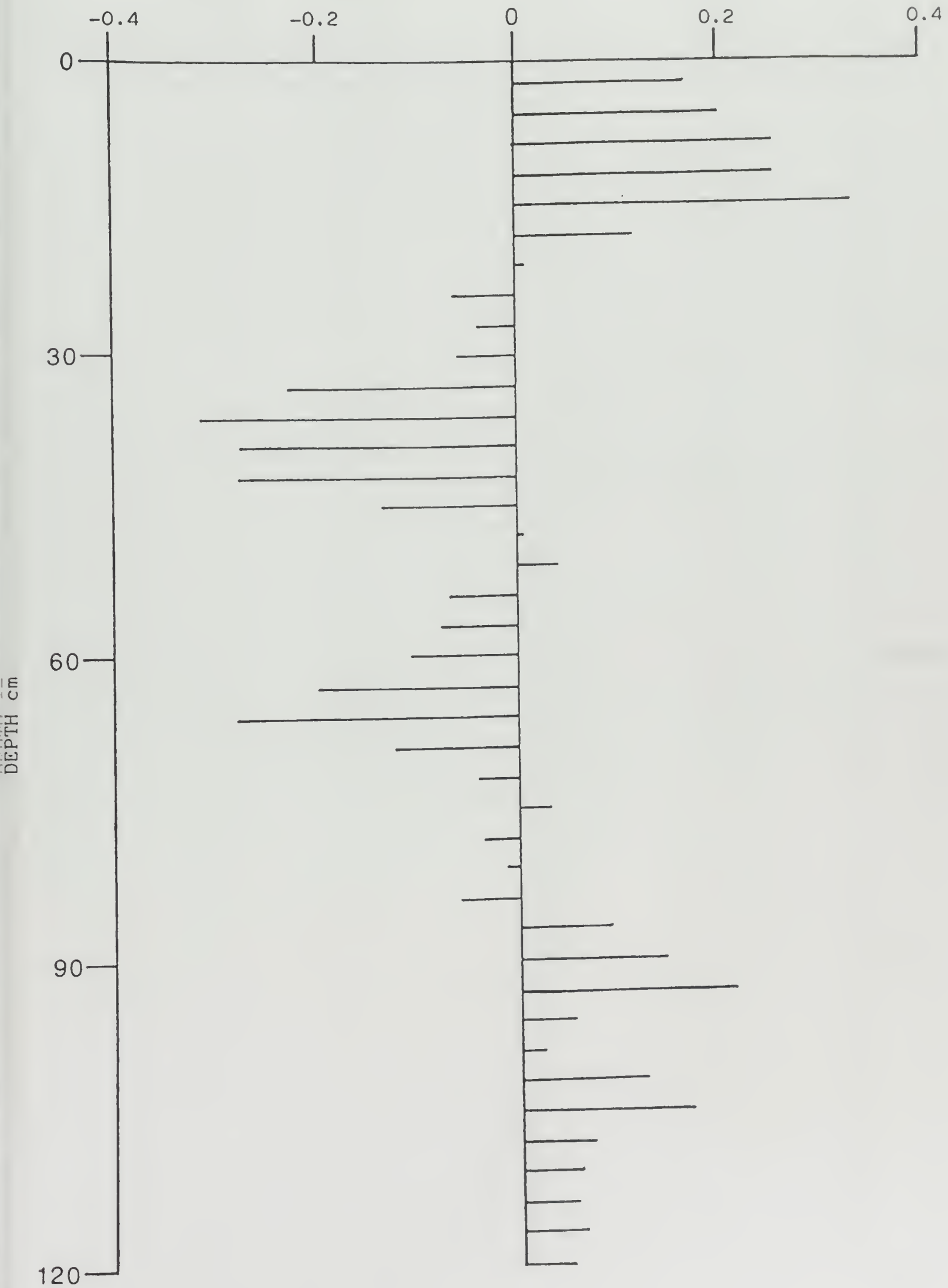


FIGURE 3. FREQUENCY DEPENDENT SUSCEPTIBILITY.

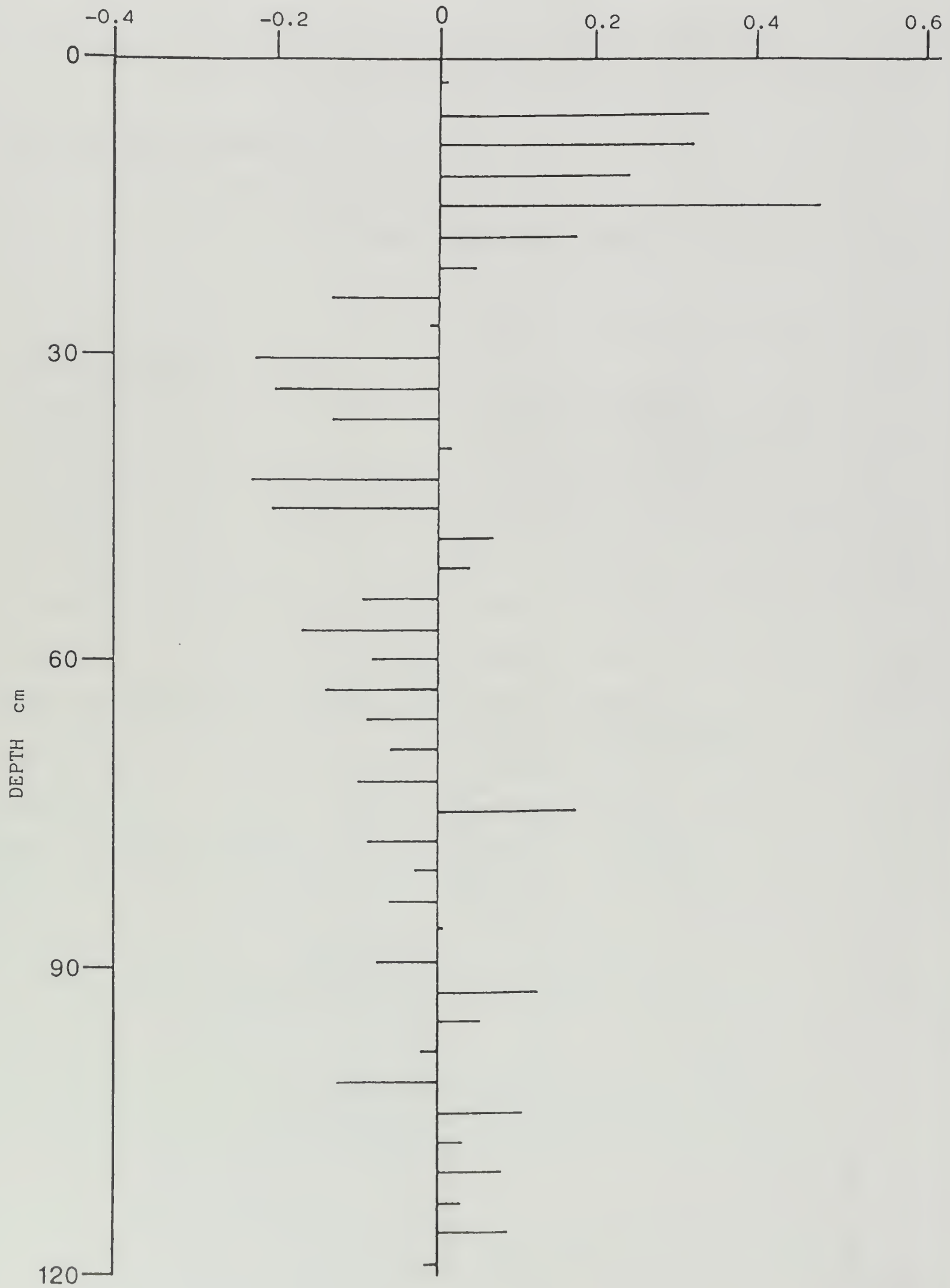


FIGURE 4. ANHYSTERETIC REMANENT MAGNETISATION.

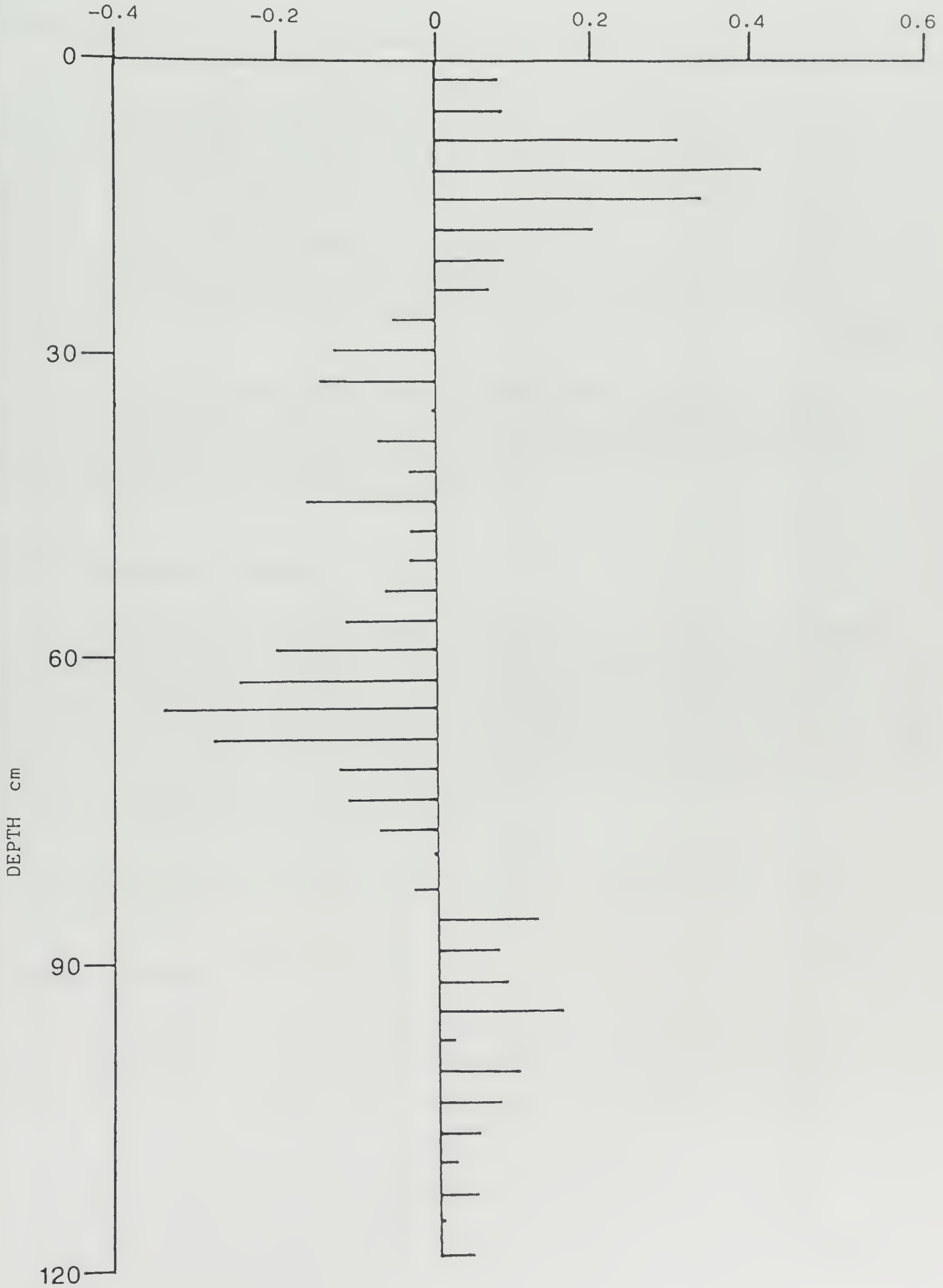
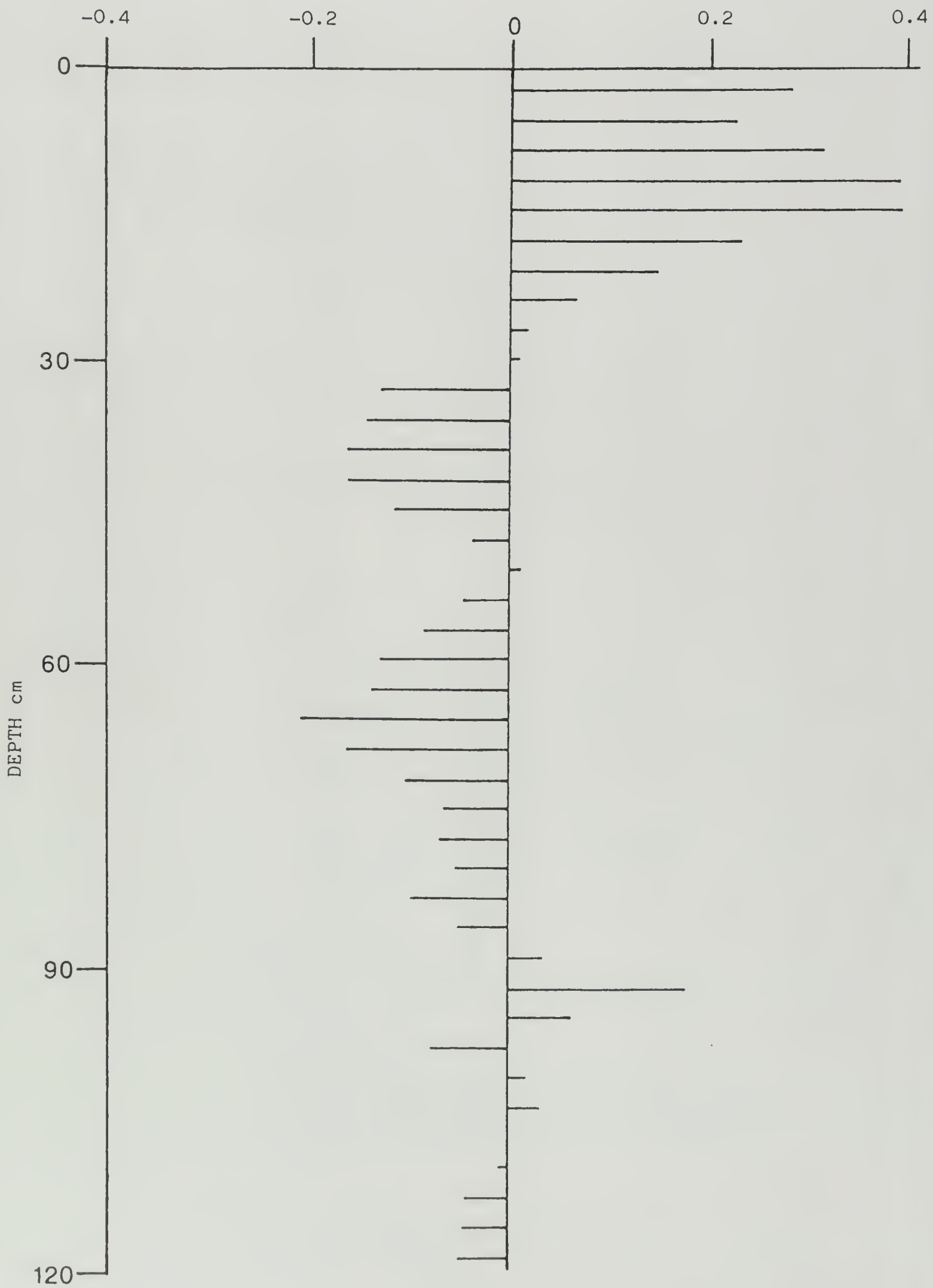


FIGURE 5. SATURATION ISOTHERMAL REMANENT MAGNETISATION.



It cannot always be assumed that the waters and transported eroded materials flow directly from the catchment to the loch, since they may pass through other lochs before they enter Loch Ness.

Study Methods

The core was sealed immediately after collection, for subsequent transportation to the School of Applied Sciences at the University of Wolverhampton. The core was extruded in the laboratory and samples were taken at 3.0 cm intervals. These samples were oven dried at a temperature not greater than forty degrees centigrade. The samples were homogenised and prepared for mineral magnetic analysis using standard methods. A standard suite of mineral magnetic measurements was carried out. On completion of these non-destructive magnetic measurements, the samples were prepared for bulk geochemical analysis by X-ray fluorescence.

The results are presented using a statistical method which normalises the data in such a way that all measurements can be presented on the same scale. This method allows the magnitude of change in the properties measured to be compared. A brief description of this method is given below.

Data Normalisation Method

The down core results of each variable are considered as a column. The Mean and Standard Deviation (standard deviation of the sample) of the column are calculated. Each element of the column has the column Mean subtracted from it. It is then divided by the Standard Deviation and the square root of the number of samples in the column. Results from this method should then fall between +1.0 and -1.0. This method is used by Walden (1990) as part of the procedure of simultaneous R-mode and Q-mode factor analysis.

The normalised data then represents either positive or negative variations from the mean of the data set.

Results and Interpretation

The four magnetic parameters (Figures 2 to 5) show three distinct zones, from the top of the core to 21 cm, from 21 cm to 84 cm, and from 84 cm to 120 cm. There are various anomalies within each zone, e.g. frequency dependent

susceptibility at 75 cm is positive, while all other parameters are negative or just positive. This can be considered as indicating the presence of viscous grains. The possible source for this is soil erosion within the catchment (Mullins and Tite, 1973).

The positive zones can be considered as having enhanced input of magnetic grains from various environmental sources, such as reduction within the loch or catchment soils, atmospheric inputs, or biological sources such as bacteria. The negative zones can be considered as the reverse, or dilution of the magnetic grains by the increased input of diamagnetic or paramagnetic sediments from the catchment (Thompson and Oldfield, 1986).

Figures 6 to 9, comprising the alkali and alkaline earth elements, calcium (Ca), sodium (Na), potassium (K) and magnesium (Mg), also show three distinct zones, which almost coincide with the magnetic zones but have the opposite sign. The positive zone implies a period of enhanced erosion in the catchment of diamagnetic or paramagnetic sediment which is diluting the magnetic grains. Na and Mg mirror the magnetic properties, whereas Ca tends to respond before the magnetic properties at a depth of 24 cm, and K responds after the magnetic properties at a depth of 15 cm.

Iron (Fe) and manganese (Mn) (Figures 10 and 11) follow the trend of three zones except for the top 21 cm of the core. Mn is increasing while Fe is close to the mean; this implies variations in redox of the sediment (Mackereth, 1966).

The heavy metals, lead (Pb) and zinc (Zn) (Figures 12 and 13) do not appear to correspond to the three zones discussed above. Closer inspection, however, shows three zones which could be considered to follow the alkali and alkaline earth elements, except for the top 33 cm.

With the advent of the Industrial Revolution (1760), certain elements were introduced to the atmosphere by the increased burning of fossil fuels; these were then deposited on the land during rainfall (Hunt, Jones and Oldfield, 1984). The enhancement of the heavy metals is considered to be the start of the Industrial Revolution, and the peak of Pb at 15 cm could be associated with the decline in the 1970s of industrial production throughout Europe.

The enhancement of the heavy metals in the sediment record can be used to estimate the deposition rate, and the date of the sediment with respect to depth. Pb and Zn results from Loch Ness show an enrichment of Pb and Zn at sediment depth of 33 cm. Therefore:

Mean depth of enhanced Pb and Zn = 33 cm

Years since Industrial Revolution = 230 years

Annual deposition rate = 33/230 = 0.14 cm per year

Deposition, however, cannot be considered as occurring at a constant rate, because of the nature of environmental processes.

Conclusions

It is considered that the results presented here show the importance of Loch Ness to the study of palaeolimnology. The 1.2 metre core is believed to encompass some 850 years of environmental history.

The heavy metals indicate the start of the Industrial Revolution in 1760 (33 cm depth). The positive zone of the alkali and alkaline earth elements may indicate the start and finish of the Little Ice Age, a cold wet period between 1500 (78 cm) and 1850 (24 cm).

Future work

The method of normalising the data presented here appears to give a qualitative representation of environmental change, with a relative representation of the magnitude of change within the sediment record. This method may be used to compare changes between different lakes. At present a sediment trap is in position in Loch Ness to collect one year's deposition. The sediment collected will then be analysed and the results will be used as the mean for the method of normalisation.

Loch Ness offers considerable scope for palaeolimnology, with respect to environmental change during the late Devensian and Holocene times.

Acknowledgements

The author would like to thank Mr. Adrian J. Shine and all colleaques at the Loch Ness and Morar Project for their assistance; also Dr. J.P. Smith, Dr. K.M. Farr and Mr. Brian Bucknall at the University of Wolverhampton for their help and advice.

FIGURE 6. CALCIUM.

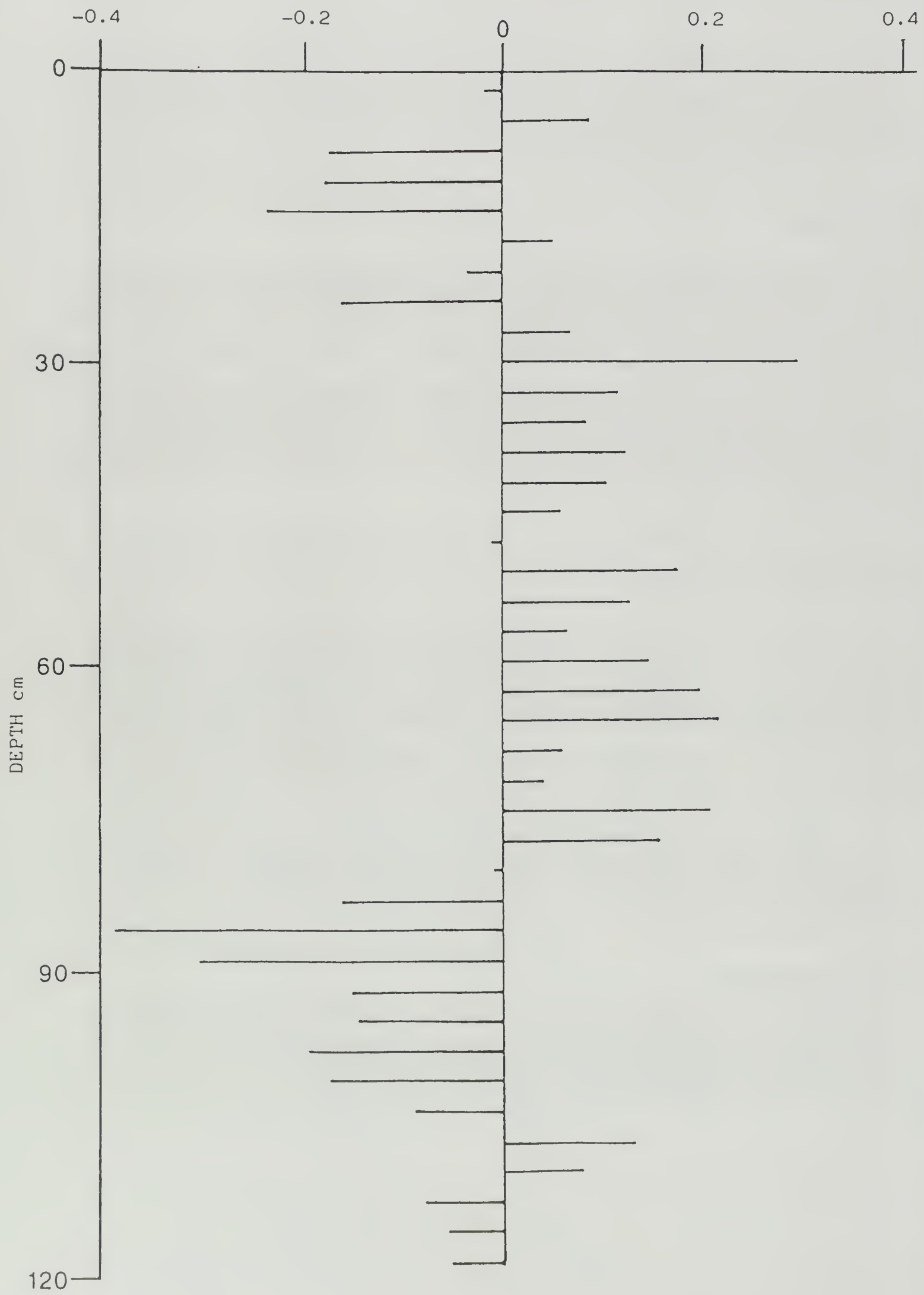


FIGURE 7. SODIUM.

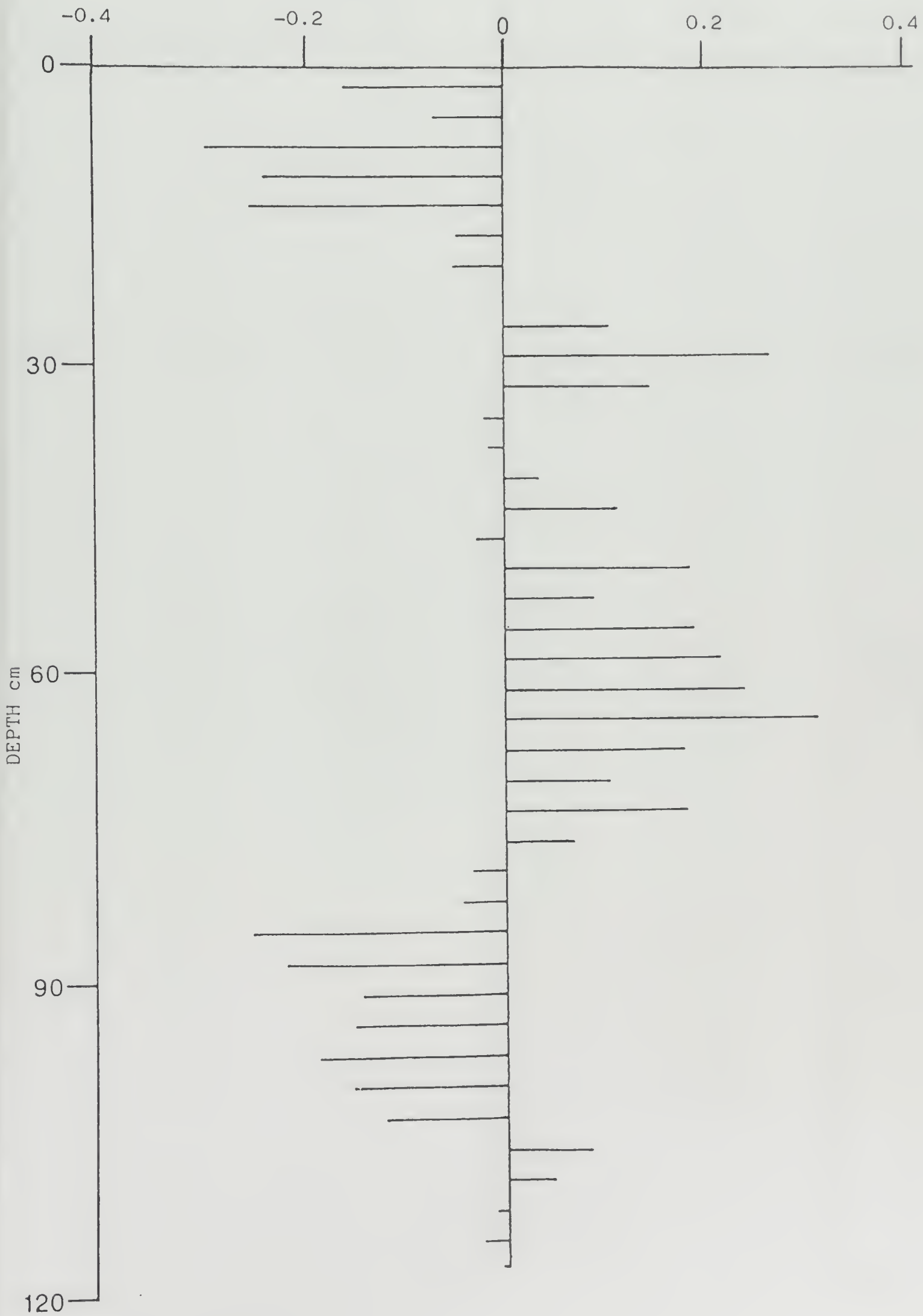


FIGURE 8. POTASSIUM.

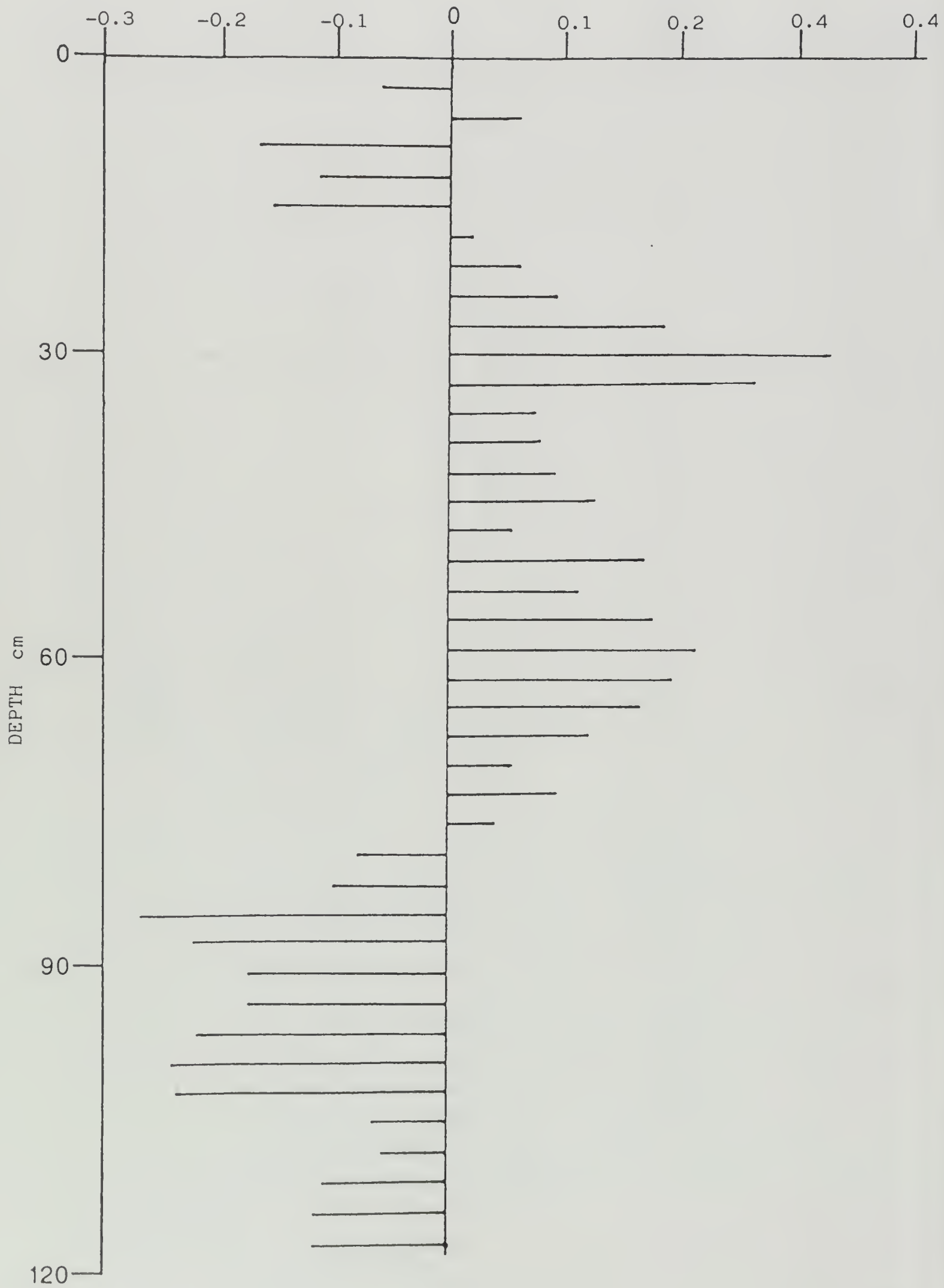


FIGURE 9. MAGNESIUM.

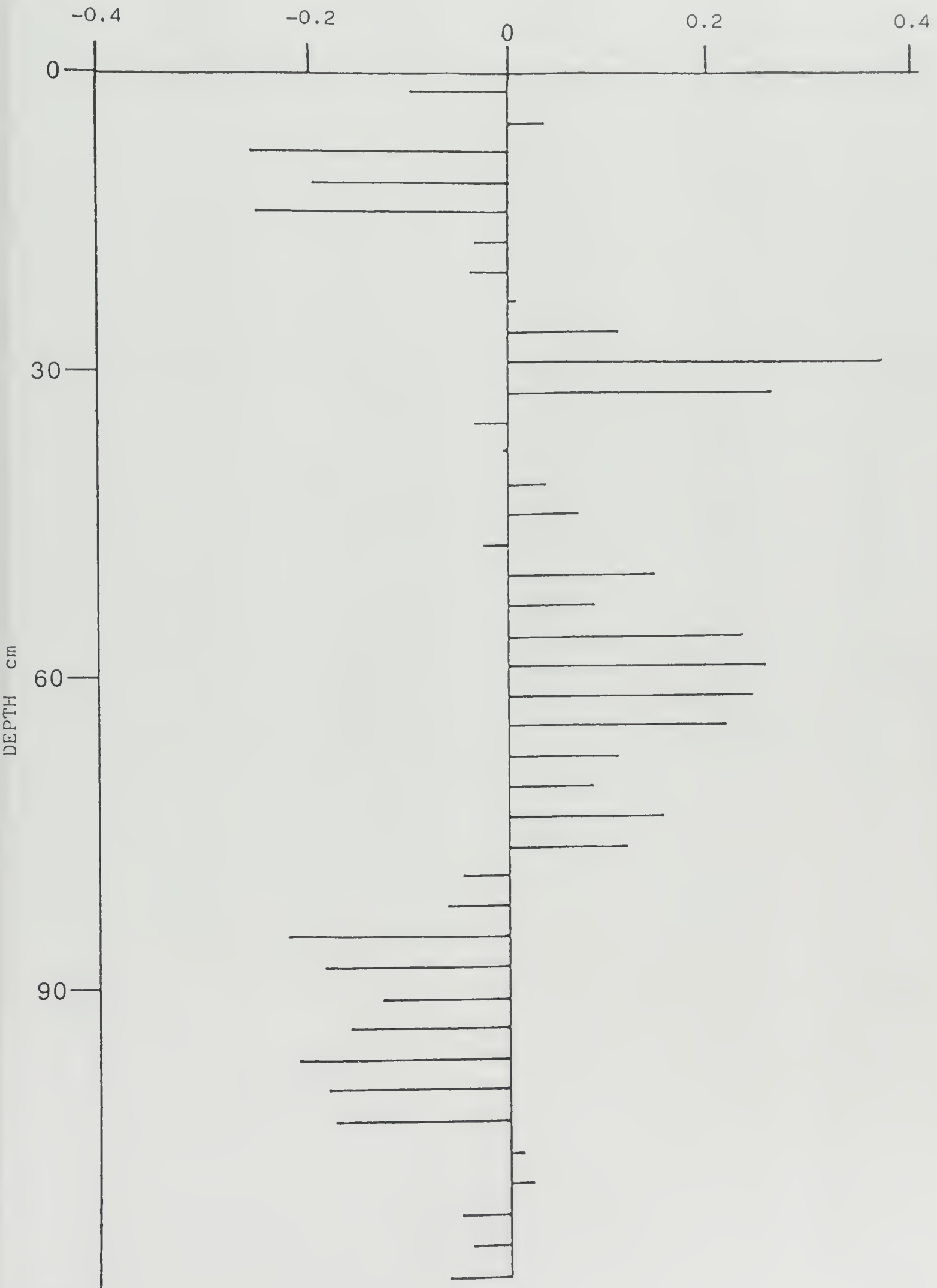


FIGURE 10. IRON.

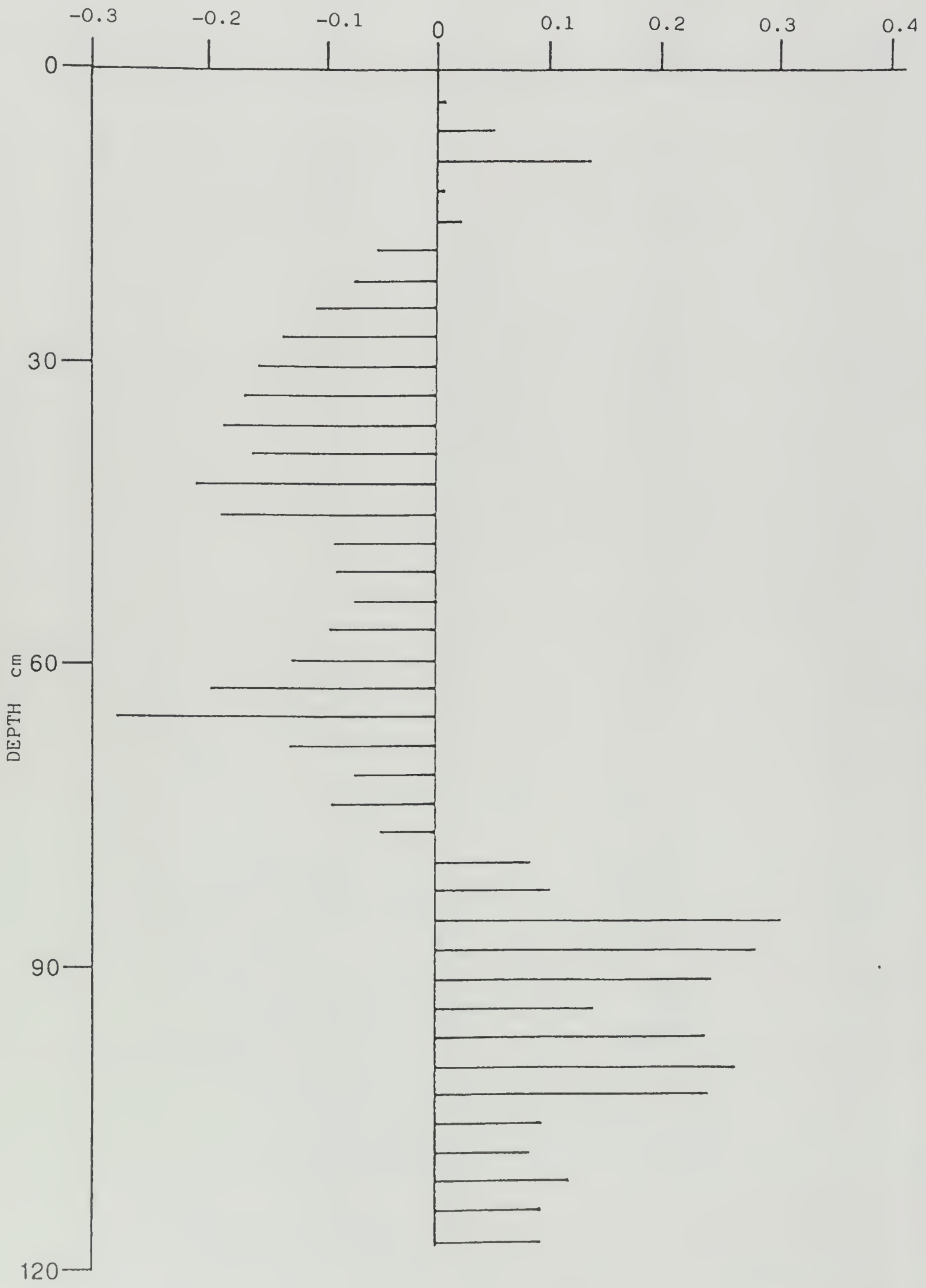


FIGURE 11. MANGANESE.

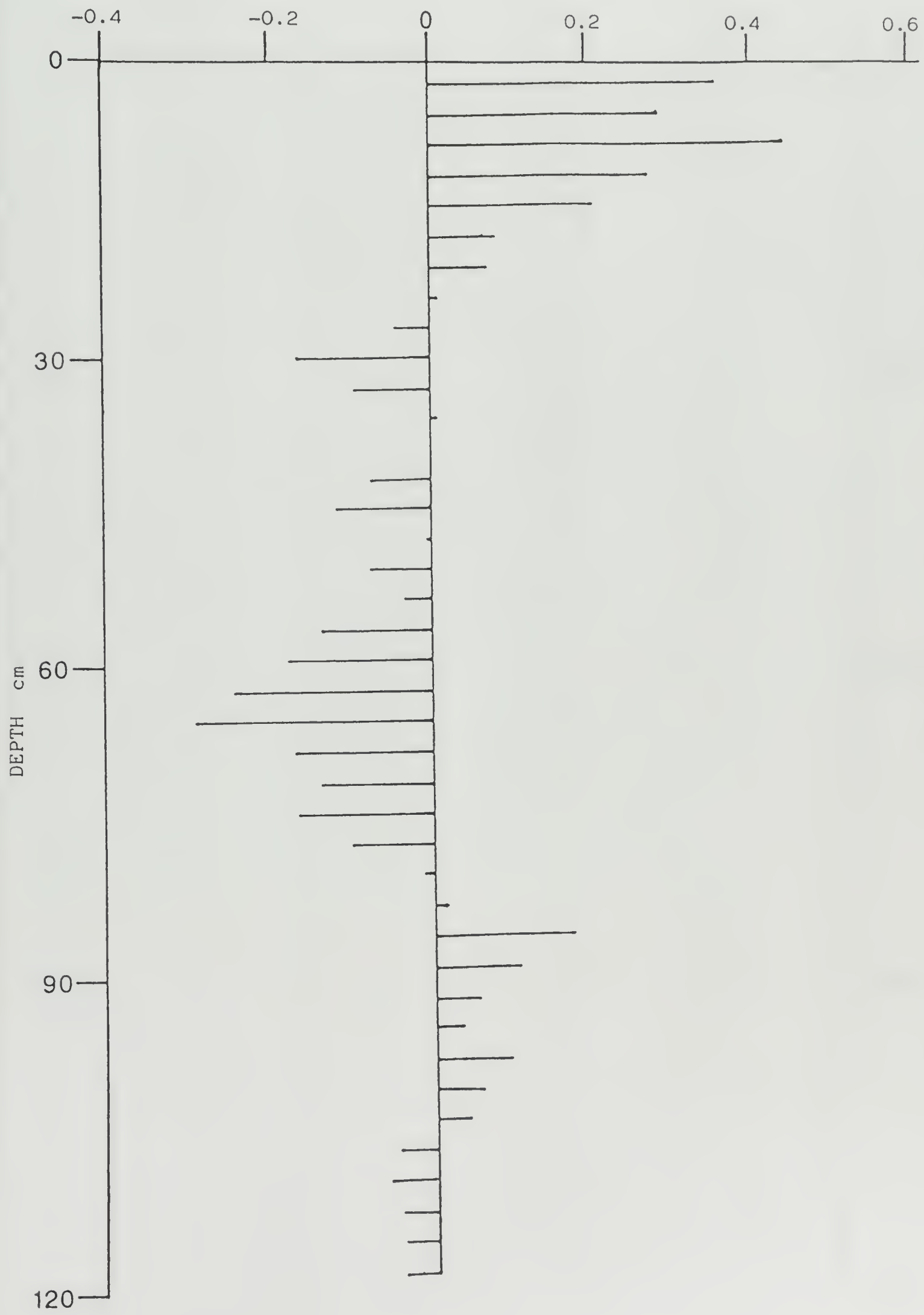


FIGURE 12. LEAD.

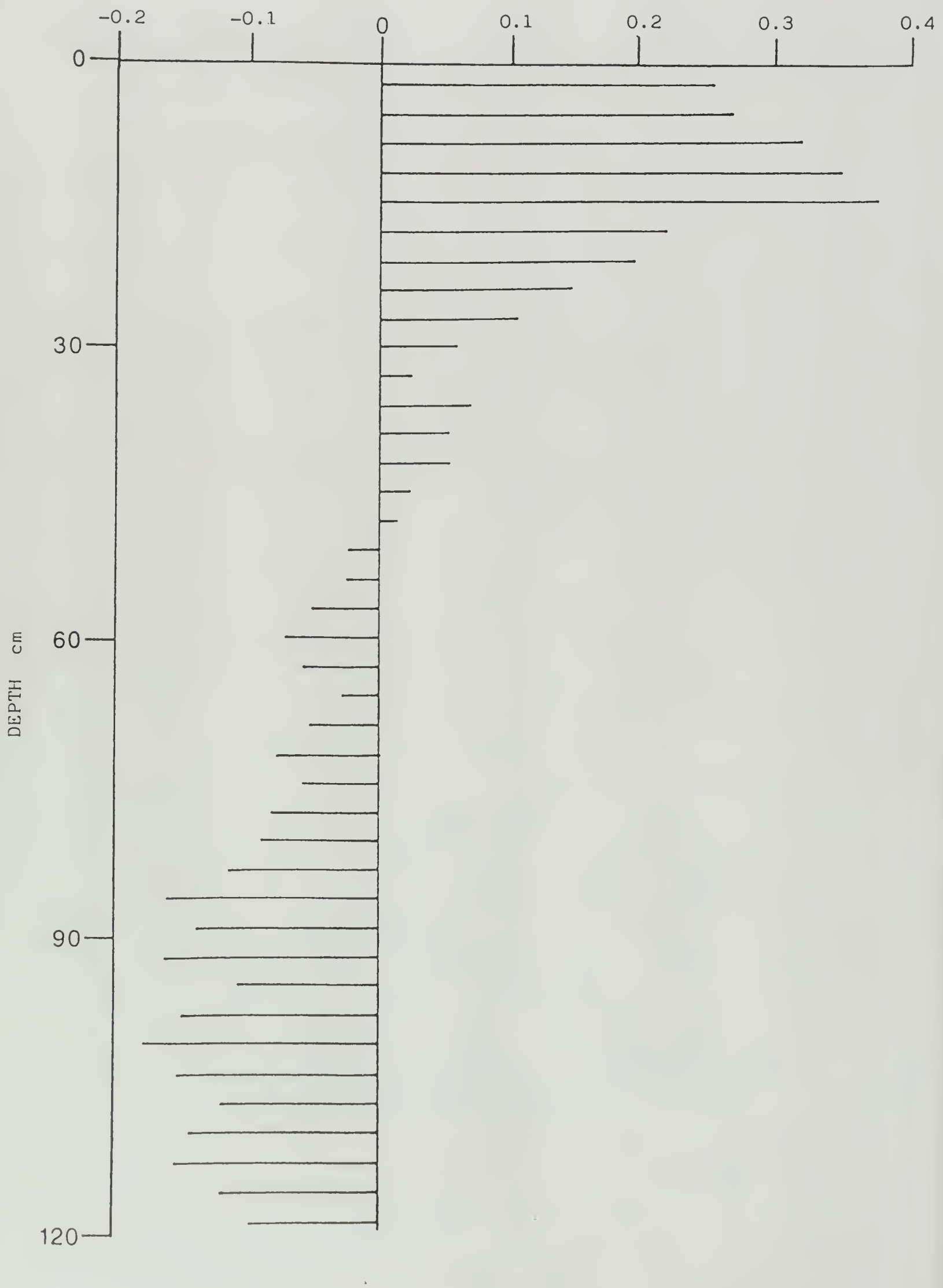
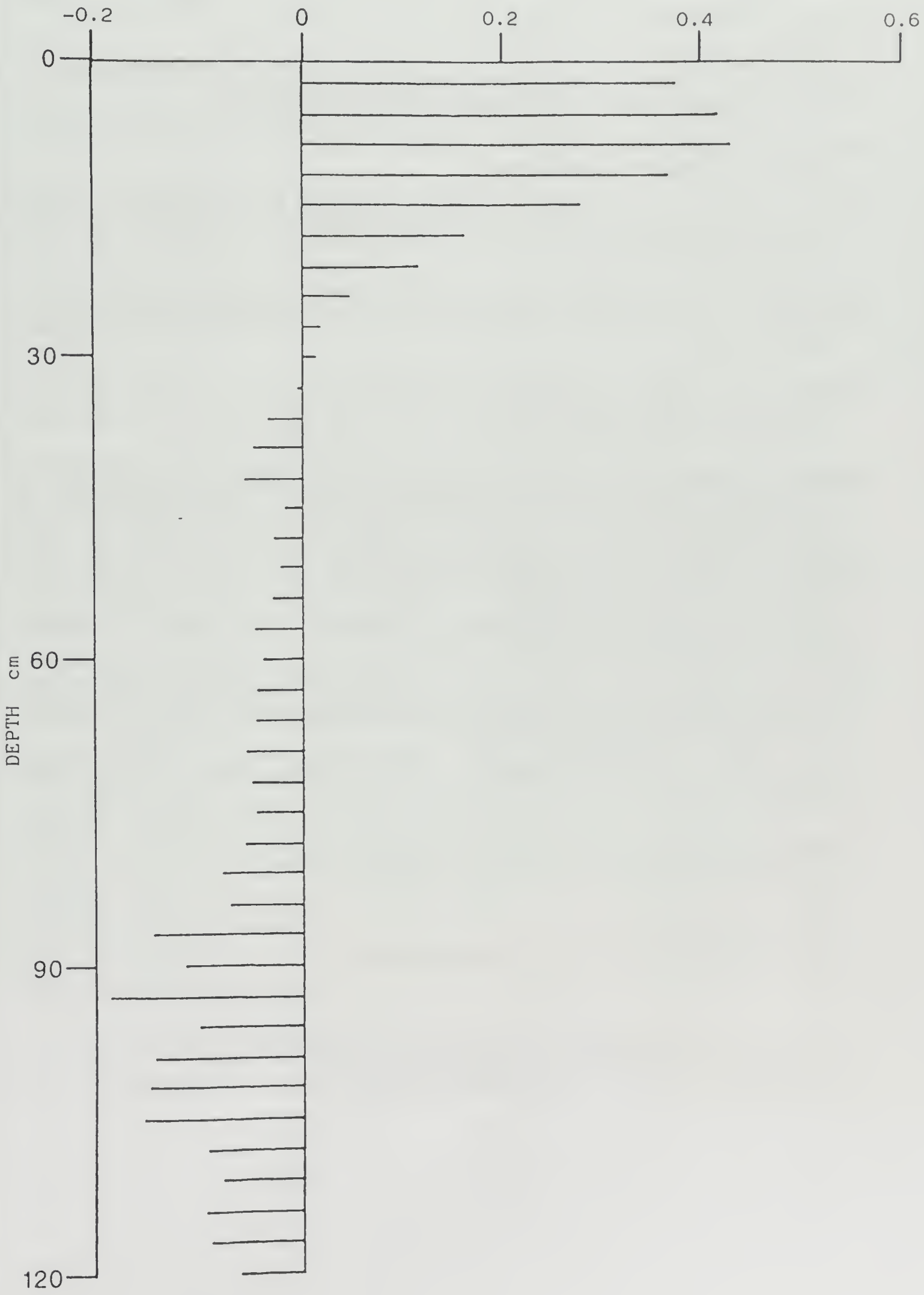


FIGURE 13. ZINC.



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Received May 1993

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THE USE OF A SEDIMENT CORE TO RECONSTRUCT THE HISTORICAL INPUT OF CONTAMINANTS TO LOCH NESS: PCBs and PAHs

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Loch Ness and Morar Project

Introduction

The activities of man in the developed world, since the inception of the Industrial Revolution in the 1760s, has resulted in widespread global contamination from a variety of elements and compounds. As environmental impact, toxicological awareness and analytical techniques have developed, so too has environmental consciousness. Following the publicity given to several pollution disasters, followed by public lobbying and governmental legislative action, programmes were initiated to improve environmental quality. Most noteworthy was the implementation of the Clean Air Act of 1956, directed at limiting toxic emissions to the atmosphere. Unfortunately much environmental and ecotoxicological damage had already been perpetrated. Heavy metal contamination was the first to receive attention, with mercury poisoning and emissions of lead from automobiles initially becoming popular avenues for research. The impact from organic compounds (i.e. those containing carbon in their structure) was not fully recognised until the late 1960s, and remained somewhat under-investigated until quite recently. Of the vast array of organic pollutants present within the environment, from natural and anthropogenic sources, few if any have been researched in as much detail as the polychlorinated biphenyls (PCBs) and polynuclear aromatic hydrocarbons (PAHs).

PCBs and PAHs are examples of ubiquitous pollutants, generally found at elevated concentrations in urban/industrialised regions, and also distributed to

remote locations by wet and dry atmospheric deposition processes and hydrospheric transport mechanisms. They have been detected at varying magnitudes in a variety of terrestrial, aquatic, and marine biotic and abiotic matrices throughout the world, which demonstrate differences in compound uptake mechanism and composition. PCBs are anthropogenic compounds, which were first produced in 1929 and found use as heat transfer fluids in electrical transformers and capacitors, and pneumatic systems. PAHs, on the other hand, although produced naturally from the incomplete combustion of fossil fuels, are indicators of anthropogenic activity, in particular heavy industrial processes. Combustion/emission controls (1950s), and usage and production bans (1970s), have been nationally and internationally imposed in an attempt to reduce releases of PAHs and PCBs, respectively, to the natural environment.

As concern relating to the environmental impact and burdens of these groups of compounds has grown, techniques have been developed to construct retrospective historical input profiles, and, in addition, to ascertain the long-term environmental response of contaminants following implementation of legislation to restrict their production and use.

Many techniques have been introduced to assess temporal changes in levels of unaltered recalcitrant pollutants, including the utilisation of peat-cores and ice-cores (M.A.R.C., 1985), and the analysis of archived materials (Jones, Grimmer, Jacob and Johnston, 1989; Jones, 1991; Jones, Sanders, Wild, Burnett and Johnston, 1992). Undisturbed dated sediment cores have also been widely used for constructing chronological pollutant trends, since lakes and oceans are ultimate deposition sites (Hites, Laflamme and Farrington, 1977; Eisenreich, Capel, Robbins and Bourbonniere, 1989; Sanders, Jones, Hamilton-Taylor and Dorr, 1992).

Historical inputs of twenty-nine individual PCB congeners and twelve unsubstituted PAHs, as determined from an undisturbed Loch Ness sediment core, are presented in this paper. Contaminant flux trends are discussed in relation to potential source and use functions, and water column losses/chemical alteration. Despite the breadth and scope of publications now available on these groups of compounds, there still remains a dearth of knowledge regarding their fate, behaviour and diagenesis in the natural environment. In addition, little knowledge regarding British and European loadings of PCBs and PAHs is presently available. As such, it is hoped that this current work will make a valuable contribution to our further understanding of the distribution and loadings of hydrophobic organic contaminants in rural British locations.

Brief Background to PCBs and PAHs

Both groups of compounds have characteristic non-polar, semi-volatile properties, ubiquitous distribution throughout the globe, and are environmentally persistent.

PCBs. Polychlorinated biphenyls, as the name indicates, consist of a biphenyl backbone, upon which are 10 available positions for chlorine (Cl) substitution (see Figure 1), giving rise to a sum of 209 different possible substitution patterns, referred to as congeners. These extend from mono-Cl compounds right through to a totally Cl substituted deca-Cl congener. Congener solubility and vapour pressure generally decrease with increasing levels of Cl substitution. Of the 209 theoretical congeners produced, it is believed that only 140 to 150 separate congeners may exist within the environment at detectable levels (Schulz, Petrick and Duinker, 1989). Ballschmitter and Zell (1980) developed a numbering system which relates a unique number (between 1 and 209) to a specific PCB congener/structure. This nomenclature system has been internationally adopted.

PCBs were first commercially produced in 1929 by the straightforward chlorination of biphenyl in the presence of a ferric chloride catalyst. The reaction mixtures produced were marketed on the basis of their average level of chlorination under the Aroclor, Askarel and Clophen trade names. The bulk of PCBs produced between 1930 and 1980 were incorporated into electrical transformers and capacitors as heat transfer fluids, because of their chemical inertness. PCBs also found use as additives in plasticising agents and carbonless copying paper. In the environment, PCBs are best known for their bioaccumulatory properties. Their apparent resistance to excretive loss, and affinity for fatty tissue, means that body burdens within lving organisms can be high, particularly in those close to the top of the food-chain with a staple diet of fish. Biomagnification factors are particularly high for seals *Phoca* sp. and Polar Bears *Thalarctos maritimus,* despite their main habitats being remote from industrial conurbations (Norstrom, Simon, Muir and Schweinsburg, 1988; Morris, Law, Allchin, Kelly and Fileman, 1989).

Chronic exposure to PCBs may lead to chloracne, a pigmentation of the skin, and possible reproductive dysfunctions have also been reported. Toxicological effects at subtle levels (i.e. those concentrations to which the vast majority of living organisms are subjected) are not clearly understood at present, and require further epidemiological investigation; however, carcinogenic and mutagenic properties have been reported (Kimbrough, 1987).

PAHs. Polynuclear aromatic hydrocarbons are emitted as by-products of the incomplete combustion of fossil fuels, and have therefore been present within the

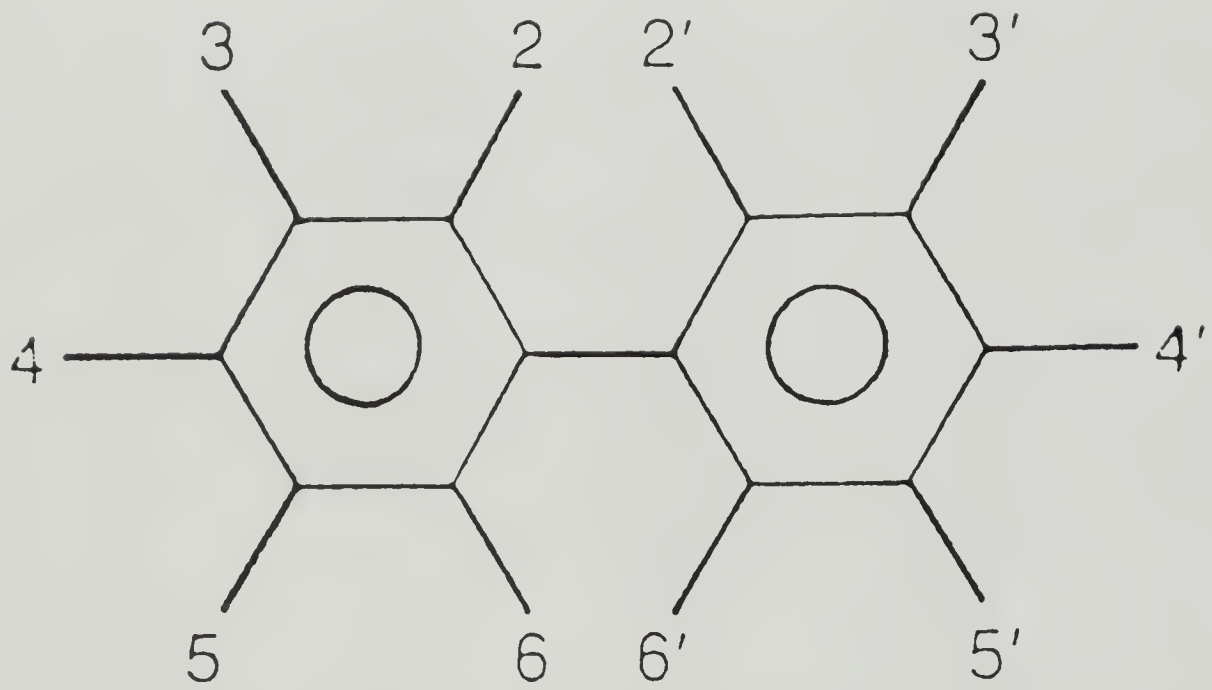


Figure 1

General structure of PCBs, illustrating positions for Cl substitution.

natural environment since at least the advent of fire. The main building block is an arrangement of fused benzene rings linked within a conjugated system. Figure 2 illustrates the structures of the twelve unsubstituted PAHs analysed for during this study. These range from the 3-ringed structure of phenanthrene (molecular weight 178) to the 6-ringed coronene (molecular weight 300). As for PCBs, solubility and volatility of PAHs tends to be inversely related to compound molecular weight. All PAHs are known or suspected carcinogens, and as such are important from a toxicological point of view. The compounds demonstrating the greatest carcinogenicity reported herein include benz[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*a*]pyrene, dibenz[*ah*]anthracene and benzo[*ghi*]-perylene (Tuominen, 1990).

Materials and Methods

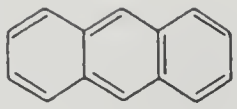
Sampling

A 1.0 m long sediment core (10.3 cm internal diameter) was obtained from the North Basin of Loch Ness, using a modified Cullenberg gravity coring device (at 57°20'N, 4°24'W; water depth 210 m) during April 1992. The sampling site was chosen to reflect an area of loch bed which is believed to be relatively flat and likely to be devoid of any major *in situ* sediment disturbances, e.g. slumping. The sediment core was sectioned immediately following retrieval, using a vertical piston extruder with 1.0 cm intervals accurately marked. Extruded sections were carefully removed from the top of the core by a specifically machined copper slicer, and were placed in labelled zip-lock plastic bags. The sectioning regime involved removal of 1.0 cm intervals from the uppermost 14 cm of the core (sections LN1 - LN14), and 2.0 cm intervals to a maximum depth of 54 cm (LN15 - LN34) thereafter. The samples were deep frozen until required for further preparation. Finally, the samples were transferred to evaporating dishes while still frozen, and were left to air-dry at ambient temperature and pressure before milling and homogenisation to a uniform fine powder.

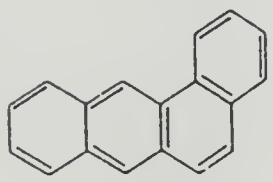
Dating

Average sediment accumulation rates, and a down-core chronology, have been determined from ^{134}Cs and ^{137}Cs caesium isotope data derived from gamma spectroscopy. Approximately 5.0 to 15 g of air-dried material, from various sections of the core, were counted for a duration of at least one day on an E.G &

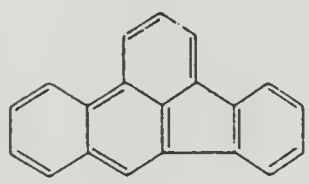
Anthracene



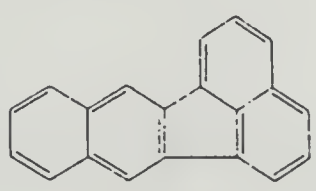
Benz[a]anthracene
= (tetraphene)
= (1,2-benzanthracene)



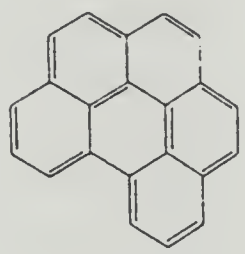
Benzo[b]fluoranthene
= (2,3-benzfluoranthene)



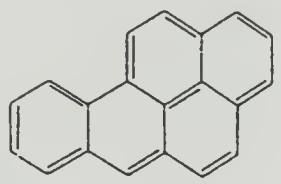
Benzo[k]fluoranthene
= (8,9-benzfluoranthene)



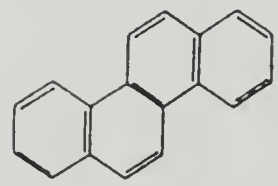
Benzo[ghi]perylene
= (1,12-benzoperylene)



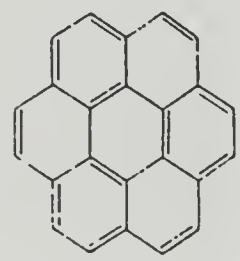
Benzo[a]pyrene
= (1,2-benzpyrene)
= (3,4-benzpyrene)



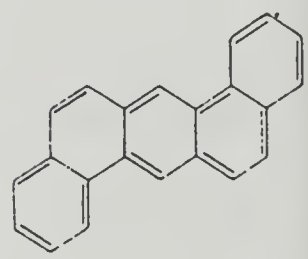
Chrysene



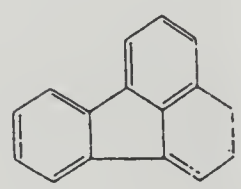
Coronene



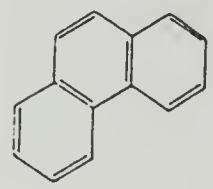
Dibenz[a,h]anthracene
= (1,2-5,6-dibenz-
anthracene)



Fluoranthene



Phenanthrene



Pyrene

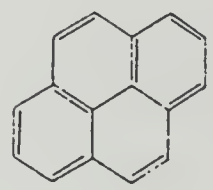


Figure 2

Structures of 12 unsubstituted PAHs determined.

G. Ortec system, employing a high purity germanium detector. Counting replication and efficiency was checked on a regular basis with spiked material.

Sample Extraction and Analysis

Between 2.0 and 10 g of air-dried sediment material in Whatman cellulose extraction thimbles, was soxhlet extracted with dichloromethane for 12 hours. Copper turnings were incorporated during extraction to remove elemental sulphur. Following extraction, the sample was split in a 2 : 1 ratio for the determination of PCBs and PAHs, respectively.

PCB Purification and Analysis: Detailed information regarding the clean-up and analytical steps employed during the determination and quantification of PCBs in sediments can be found in Sanders *et al.* (1992). In summary, matrix interferences are removed on a Florisil column, PCBs are eluted with hexane, concentrated to 0.5 ml, and analysed by high resolution capillary gas chromatography equipped with electron capture detection (HRGC-ECD). Identification and quantification of PCBs was achieved by overlaying the chromatogram of a standard mix containing 51 individual congeners, and matching and naming peaks by their retention times. This step was performed automatically using a VG Minichrom data processing package. The 49 congeners present in the composite PCB standard were, in order of elution, Nos. 3, 10, 6, 8, 14, 30, 18, 15, 54, 28, 52, 104, 44, 37, 61/74, 66, 155, 101, 99, 119, 77/110, 82/151, 149, 118, 188, 153, 105, 138, 126, 187, 183, 128, 185, 202, 156, 204, 180, 169, 170, 198, 189, 208, 194/205, 206, 209. Of the 49 congeners screened for, 30 have been quantified and are reported here. The results are discussed with respect to the sum of these 30 congeners (ΣPCB).

PAH Purification and Analysis: Details of the procedures involved in the clean-up and analysis of PAHs have been comprehensively described (Sanders, Jones, Hamilton-Taylor and Dorr, 1993). Briefly, samples were cleaned-up on a column of Florisil, and all unsubstituted PAHs eluted with dichloromethane. The eluent was reduced to 0.5 ml, and 2.0 to 5.0 µl was injected into a high performance liquid chromatography system (HPLC) interfaced to a fluorescence detector. PAHs were identified and quantified by comparing the retention time of eluted peaks in samples to those in a composite standard. In total, 12 PAHs were quantified and are reported in this paper; in order of elution, these were phenanthrene, anthracene, fluoranthene, pyrene, benz[*a*]anthracene/chrysene (co-elute), benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, dibenz[*ah*]anthracene, benzo[*ghi*]perylene and coronene. Derived data is discussed in terms of ΣPAH.

Results and Discussion

Dating

Average sediment accumulation rates have been calculated, and dates applied to each section using the ^{134}Cs and ^{137}CS activity/depth relationships illustrated in Figure 3. These plots show some basic chronological marker layers: the surface of the core is assumed to date as 1992; corresponding ^{134}CS and ^{137}Cs maximum activities, occuring at a depth of 2.5 cm, are representative of radio-isotope releases from the Chernobyl accident on 1st May 1986; a further sub-surface maximum of ^{137}Cs at 9.5 cm, albeit a squat, diffuse peak, is indicative of the most concentrated period of nuclear weapons testing, which took place between 1963 and 1964. Although the Cs isotope method of chronological application is limited to post-1960 use, an average rate of sedimentation has been invoked between the section corresponding with 1963/64 and the bottom of the core. To assist in this assumption, a distinct clay marker layer, ubiquitous to the entire loch bed, to differing magnitudes (Bennett, 1993), and occuring at a depth of 33 cm in this core, has been utilised. This band is significant, and has been radiometrically dated at approximately the late 1860s/early 1870s (Bennett, 1993), and is believed to have resulted from grossly increased suspended particulate material loadings entering the system from the great flood of 1868 (Anon., 1868; Barron, 1985). With the current absence of data for ^{210}Pb, the naturally occurring radio-isotope, the allocated chronology must be viewed with some ambiguity. However, it is believed that the core has been sufficiently resolved, and that *in-situ* sedimentary processes (e.g. mixing) may be the dominant source of error while constructing time trends.

PCB Time Trends

The ΣPCB concentration/depth, and estimated flux/year profiles, derived from the analysis of the Loch Ness sediment core, are illustrated in Figures 4a and 4b respectively. ΣPCB is defined as the sum of the 29 congeners, Nos. 82/151 (co-elute), 99, 101, 105, 77/110, 118, 119, 128, 138, 149, 153, 155, 156, 170, 180, 183, 185, 187, 188, 189, 194/205, 198, 202, 204, 206 and 208 - all congeners contain ≥5 chlorines. U.K. PCB production data is also provided in Figure 5. Fluctuations in PCB levels are apparent with time and depth (Figures 4a and 4b), inferring temporal changes in loadings entering the Ness system. Traces of PCBs are evident throughout all the core sections extracted (down to a depth of 29 cm, approximately corresponding to the year 1890), with levels constituting

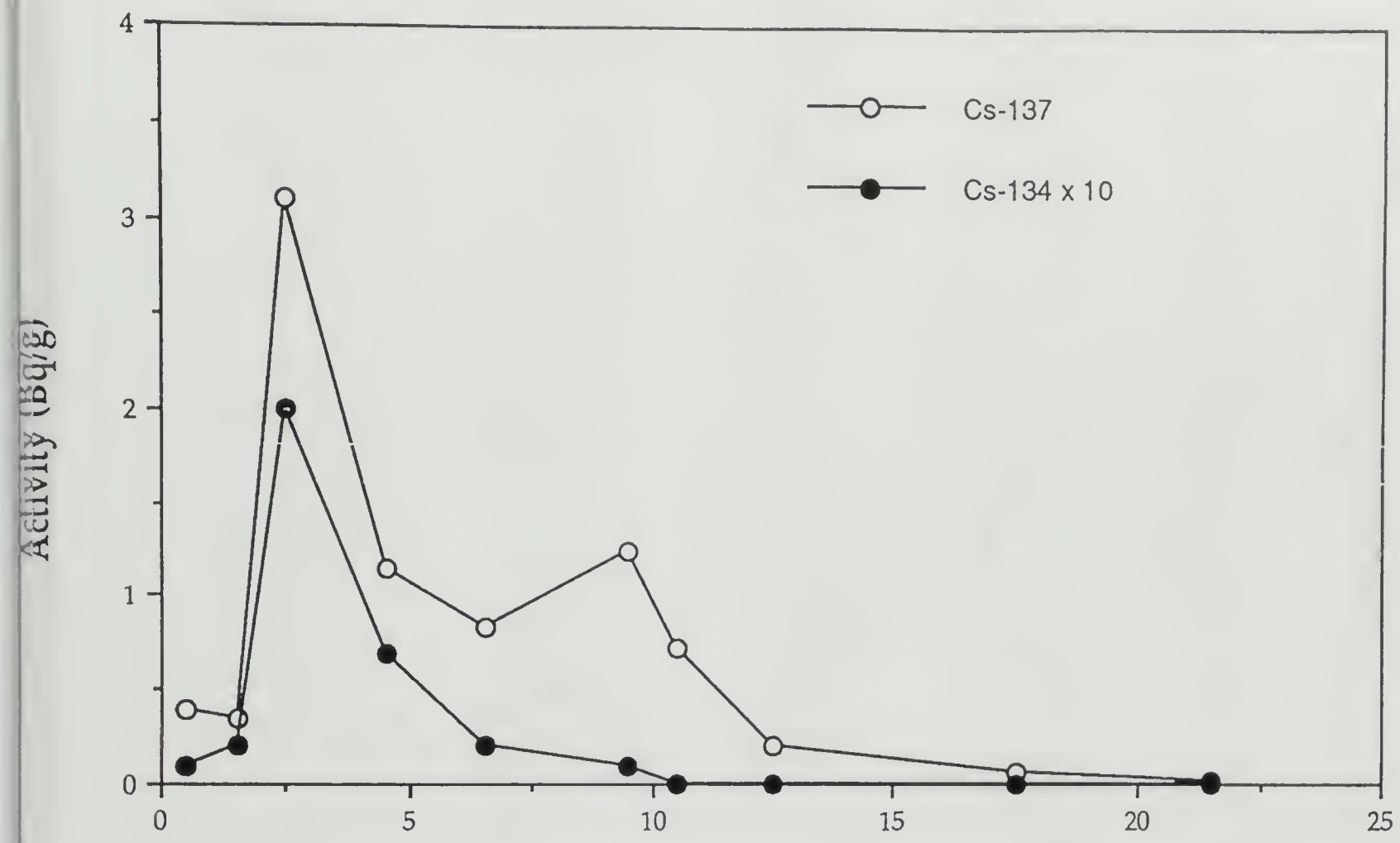


Figure 3

^{134}Cs and ^{137}Cs activity in the Loch Ness core.

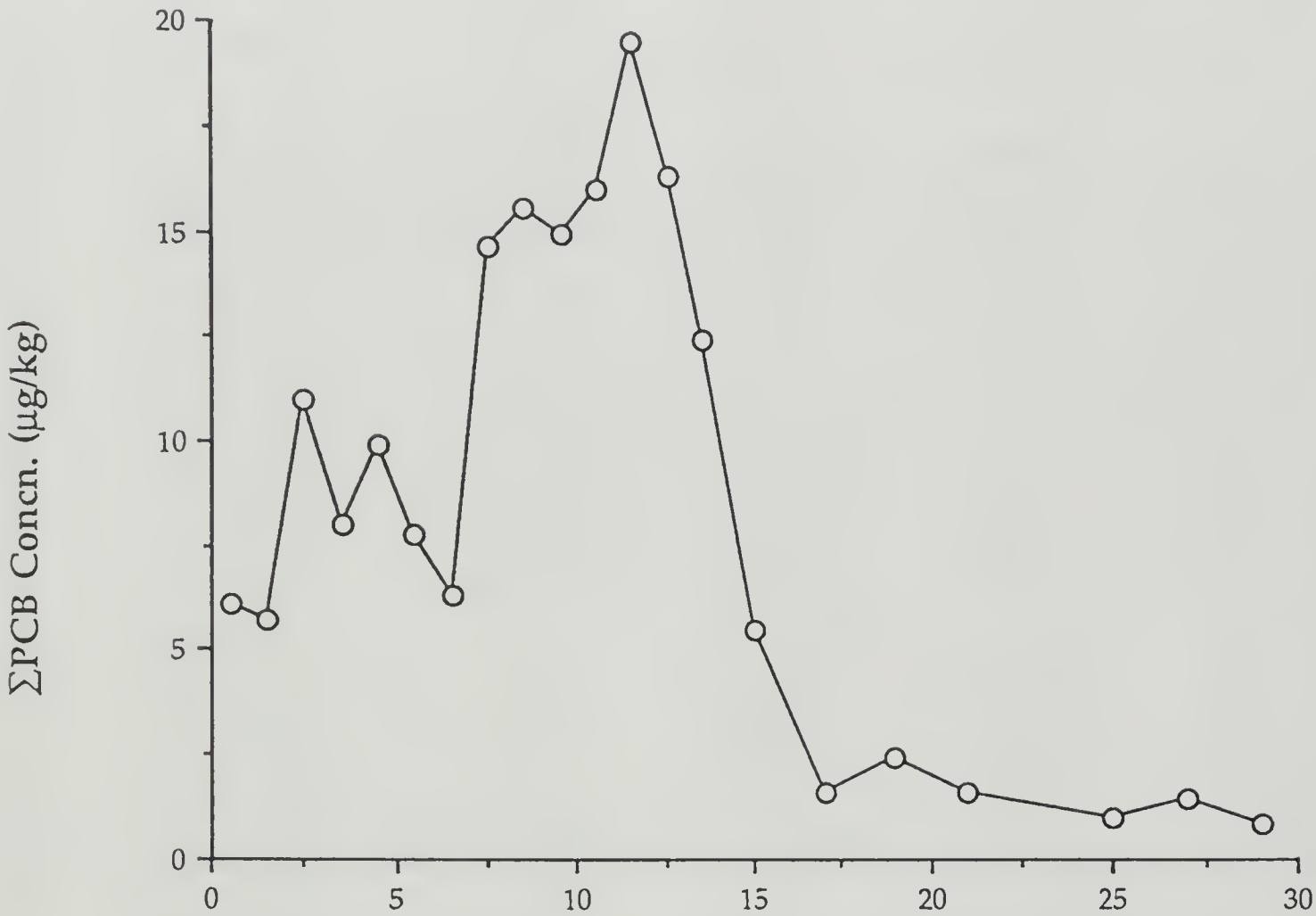


Figure 4a

ΣPCB concentration/depth profile.

Figure 4b

ΣPCB flux/year profile.

approximately 1.0 μg kg^{-1} (i.e. 1.0 part per billion). However, PCB mixtures were not commercially produced until the 1930s, thus suggesting that levels found at the base of the core, pre-dating this period, may have resulted from:

(1) Misallocation of ^{134}Cs and ^{137}Cs derived chronology,

(2) *In situ* transport and diffusion down the core following compound deposition,

(3) Contamination of deeper core sections during extrusion, due to smearing effects on the core tube wall,

(4) Adsorption of PCBs from ambient air during air-drying of material, or

(5) A combination of all these processes.

Point (4) seems most likely to be responsible for this observation, since 90% to 95% of all atmospheric PCBs exist in the free gas-phase (Manchester-Neesvig and Andren, 1989).

Initial increases in loadings of PCBs are first observed around 1945, corresponding to a depth of 15 cm. Thereafter, the sediments show a sharp escalation in ΣPCB concentration and flux loadings, demonstrating a maximum input function between 12.5 and 7.5 cm, approximately 1954 and 1972. Peak input was established at about 1958, 11.5 cm below the core surface. Since the mid-1970s inputs of PCBs to Loch Ness and the Ness catchment system have shown a significant reduction. Indeed, when compared against average concentrations and fluxes of PCBs sedimented out during the period of maximum input, the core data suggests an average decrease of 52% in sediment concentrations, which translates to a drop of around 37% in flux delivery, over the past 20 years.

The PCB input function determined from the Loch Ness core (Figures 4a and 4b) illustrates some anomalous characteristics with U.K. PCB production figures (see Figure 5). Production in the U.K. commenced in 1954, and peaked in the mid-1960s to late-1960s. Approximately half of all PCBs produced in the U.K. were incorporated into 'closed' system transformer and capacitor usage. Prior to this, small quantities had been imported, for promotional use only (Bletchly, 1983). Higher than background levels of PCBs are, however, detected in the early-1940s, suggesting either that long-range transport and deposition of hydrophobic

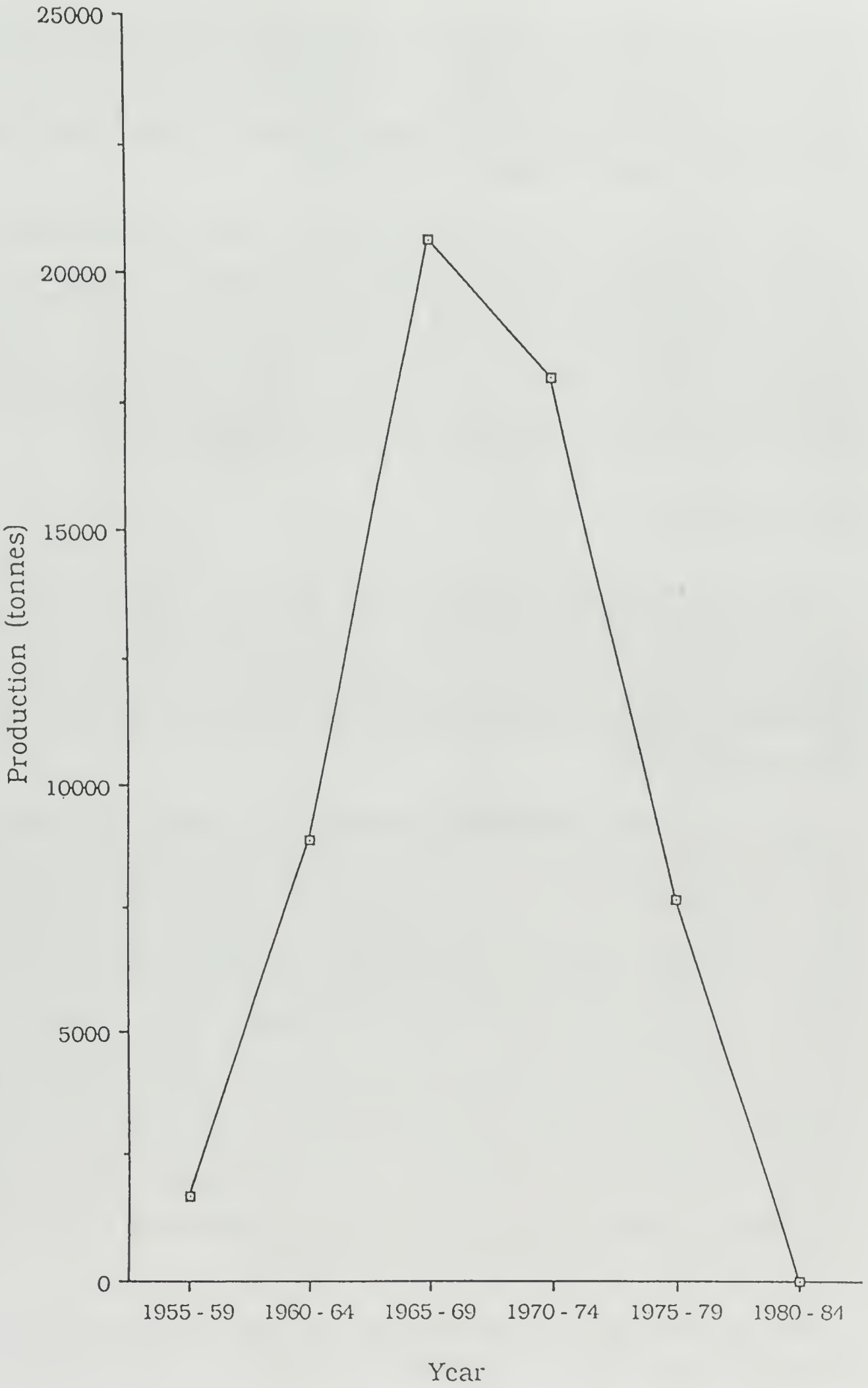


Figure 5

PCB production figures for the United Kingdom.

contaminants is significant within this rural region, and/or that temporal resolution within the core is insufficient to allow complete deconvolution of the contaminant input record. Despite pre-1950 loadings, core inputs demonstrate good agreement with the pattern of PCB production - United Kingdom PCB production peaked in the mid-1960s to mid-1970s (Figures 4a, 4b and 5).

Recent declines in environmental loadings of PCBs reflect national and international legislation and bans on usage and production, implemented in the 1970s. Enhanced levels at or near the surface of the core may represent a recent increase in loadings, or inputs of 'fresh' material which have not yet undergone diagenetic processing (Sanders, 1993). The latter phenomenon will be discussed in the following sections. It is, however, expected that levels of PCBs entering the sediment of Loch Ness will continue to drop for the forseeable future.

PAH Time Trends

PAHs have been present within the natural environment since the advent of fire, and as such have been determined and quantified throughout the entire length of the core. Figures 6a and 6b give concentration/depth, and flux/year relationships, for the sum of 12 unsubstituted PAHs to a depth of 54 cm, representing a historical record spanning from the present day back to the beginning of the 1800s.

Similar to the PCB profile, major changes in the sedimentary loadings of PAHs are obvious during the 180-year time period encapsulated (Figures 6a and 6b). ΣPAH concentrations found at the base of the core constitute sub-part per million levels. It is likely that these loadings are indicative of pre-Industrial Revolution baseline levels (53 to 37 cm depth). A marked increase in inputs is apparent at a depth of 35 cm in the core, presumably a direct response to the increased consumption of coal and wood, linked with the expansion of mechanisation and productivity, generated during the Industrial Revolution. Concentrations and fluxes of PAHs incorporated into bottom sediment rapidly multiplied to some nine times above background levels in the space of less than 50 years. Greatest inputs occur about 1922 (6.4 mg per kg^{-1}), prior to a 25% reduction seen over the following 15-year period. This sudden drop may reflect the decrease in heavy industrial manufacturing processes and general socio-economic hardship endured during the Great Depression.

After demonstrating a further sub-surface maximum in the mid-1940s (15 cm), sedimentary inputs begin to show significant reductions in levels incorporated into

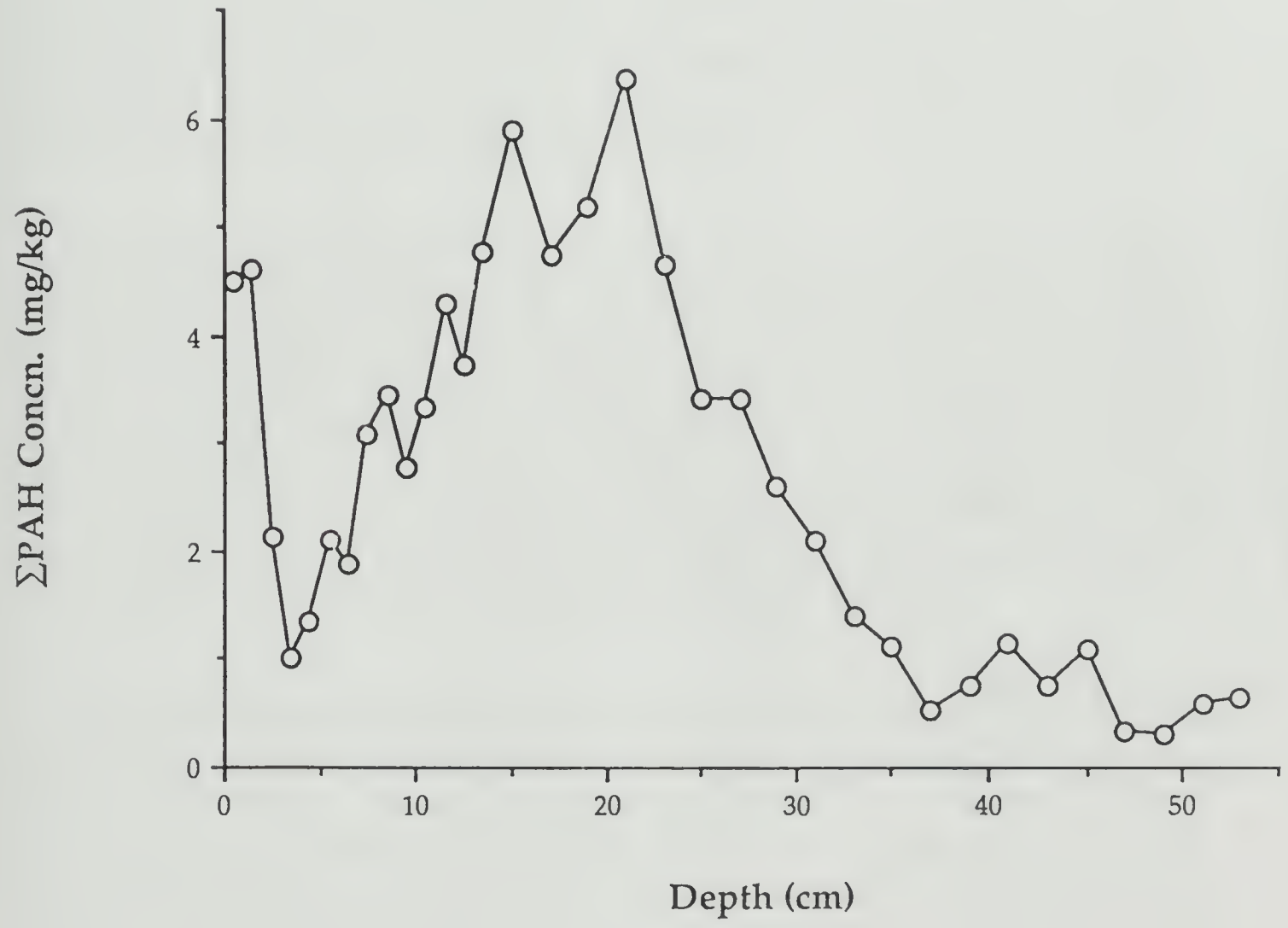


Figure 6a

ΣPAH concentration/depth profile.

Figure 6b

ΣPAH flux/year profile.

bottom sediment. Declines are especially evident from the late-1950s and prevail until the early 1980s, where inputs are slightly higher than background, representing an 84% reduction from maximum inputs. Despite evidence suggesting a marked improvement in air quality over the past 30 to 40 years, the uppermost 3.0 cm of the core show a net increase in PAH flux to the loch bed. The reasons for this are unclear, but may be related to recent point source release(s), or supply of 'fresh' unprocessed material.

The primary source of PAHs to the environment is the combustion of coal. It is likely, however, that the impact of this source has diminished significantly since the introduction of new 'cleaner' residential heating methods (e.g. gas-fired and electrical central heating), and improved combustion efficiencies in power generating plants. Figure 7 illustrates the pattern of coal consumption from the mid-1800s to the present day for the United Kingdom, and compares the relative importance of domestic and electrical generation uses throughout this period. The patterns of consumption and usage correspond well with the sedimentary record of PAHs found in the Loch Ness core (Figures 6a and 6b).

Worth noting is the rapid growth in coal consumption from 1860, which escalates to an initial maximum spanning 1900 to 1920, approximately. Following the onset of the Great Depression, the burning of coal shows a significant drop, before becoming re-established in the early 1930s. The sedimentary response to these fluctuations tends to be non-synchronous, and date slightly later than the date when the events actually took place. It is likely that this effect is a combination of biotic mixing of the bottom sediment, and a source-transport-deposition time lag.

Despite sediment loadings illustrating a peak input at around 1945, and subsequent reductions thereafter, coal consumption actually showed an increase to a maximum in the early 1950s, and maintained a high turnover until the late 1960s. Coincidentally, the trend of usage changed markedly at this point in time. Until the mid-1940s to early 1950s the dominant uses of coal were associated with many small point sources employing inefficient combustion processes, e.g. residential heating and industrial on-site electricity generating. The introduction of the Clean Air Act in 1956 proved to be successful in restricting the effect of small point source pollution emissions. In addition, the implementation of this legislation served to increase the number of central electricity generating plants, which utilised relatively efficient high-temperature combustion techniques. These measures, in combination with a gradual decline in heavy industry, have resulted in an overall reduction in PAH emissions.

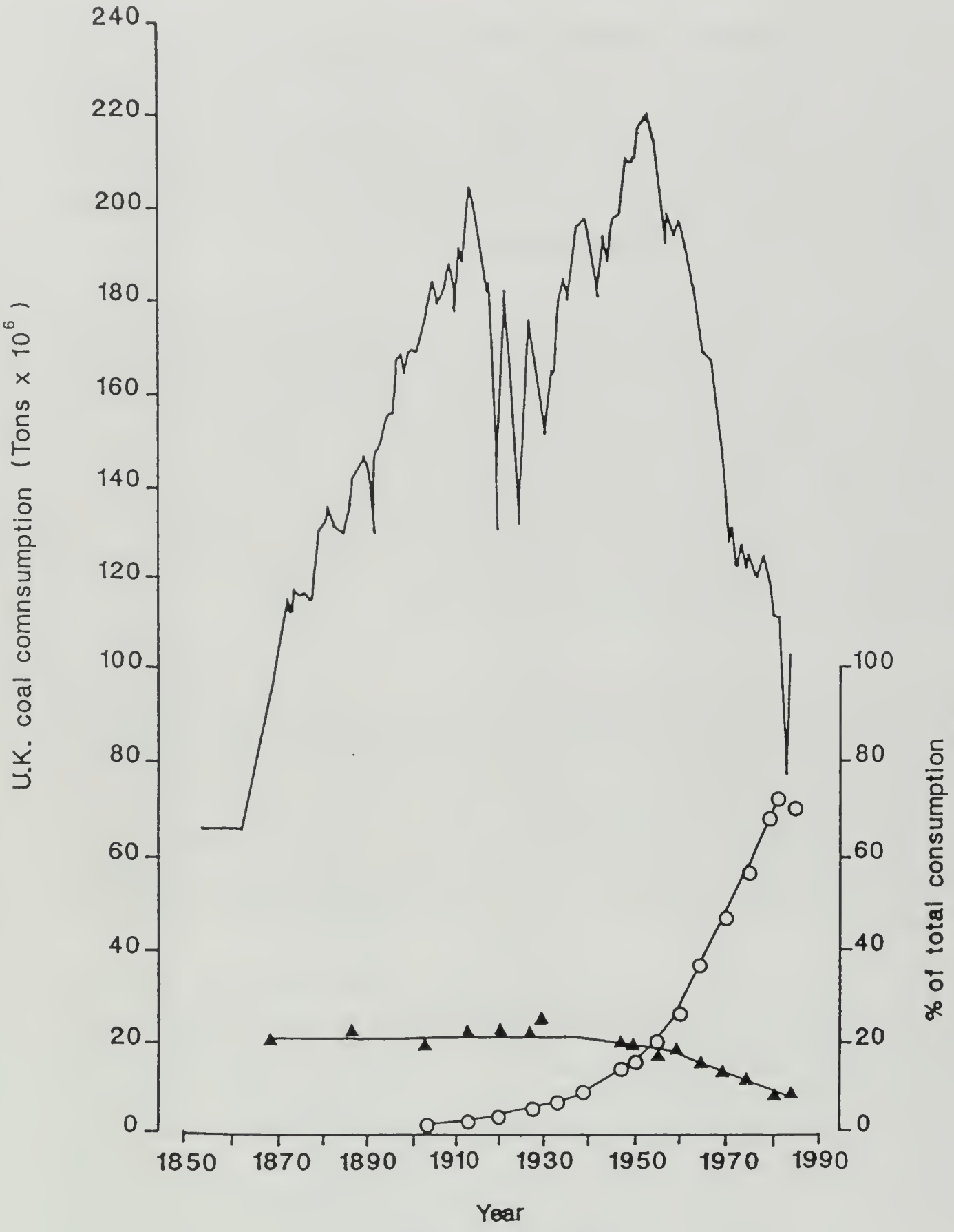


Figure 7

United Kingdom coal consumption from the mid-1800s to the present day. Also shown are the percentages of total consumption used domestically (▲) and for electricity generation (o).

PCB and PAH Contamination in the Sediments of Loch Ness

In the absence of reliable data regarding past environmental loadings of contaminants, it is often advantageous to employ retrospective assessment techniques in order to build a picture of temporal pollution trends. In this capacity the use of dated lacustrine sediment cores has proved valuable (Hites *et al.*, 1977; Wickstrom and Tolonen, 1987; Eisenreich *et al.*, 1989; Sanders *et al.*, 1992 and 1993).

Table 1 compares the present Loch Ness data to historical PCB and PAH trends determined from various other sediment cores in Great Britain and North America, with emphasis on key time-points and significant changes in environmental burdens. Of the four cores, Loch Ness shows the latest onset in increases of PCB contamination (15 to 20 years later than the other examples), while demonstrating a slightly earlier response to the onset of the Industrial Revolution than the Esthwaite Water core (from PAH data, Table 1). Unfortunately the Lake Ontario cores analysed were not sufficiently deep to resolve pre-industrial baseline levels. The period of maximum PCB and PAH input also differs from core to core. PCB maxima vary from 1958 (Loch Ness) to 1970 (Lake Ontario, G-32). It is more pertinent, however, to consider the time-span duration of highest PCB input, and draw comparisons by this means.

Employing this approach identifies a 20-year window, during which time PCB maxima occured in all cores. PAH maxima also illustrate a slight diversity in temporal correlation between cores. There are two maxima in the Loch Ness core, corresponding to 1922 and 1945. In Esthwaite Water and the two Lake Ontario cores, highest inputs are seen at 1952, 1949 and 1948, respectively. The onset in reductions in PAH inputs to Loch Ness do, however, correspond well with that observed in both Lake Ontario cores. Finally, declines in environmental loadings of PCBs and PAHs are corroborated by all examples. Current fluxes of PCBs, relative to maximum inputs, to Loch Ness, Esthwaite Water, Lake Ontario E-30 and G-32 are 50%, 40%, 70% and 60% respectively. Despite recent near surface increases in PAHs in Loch Ness, levels here have fallen 80% from maximum inputs. Reductions in Esthwaite Water and both Lake Onatrio cores are 60%, 70% and 70%. Although much improvement in sediment quality is evident, which presumably is transposable to other environmental compartments, present-day loadings still remain many times greater than background contamination levels.

The amount of PCB and PAH contamination found in the Loch Ness core tends to reflect the relatively rural location of Loch Ness and its remoteness from large residential and industrial conurbations. Maximum PCB fluxes to Esthwaite Water,

Table 1

Summary of PCB and PAH time trends derived from dated sediment cores obtained from Loch Ness (North Scotland), Esthwaite Water (North-West England) and Lake Ontario (North America).

Location	Date Sampled		Year of Onset	Year of Max	Year of Span[a]	Ratio of Fluxes Pres : Onset	Ratio of Fluxes Max : Onset	Ratio of Fluxes Pres : Max
Loch Ness,	April, 1992	**PCBs**	1945	1958	1950-1972	5.9	11.9	0.5
N. Scotland		**PAHs**	1874	1922	1915-1950	4.0	3.8	1.0
Esthwaite Water,	Feb., 1990	**PCBs**	1929	1963	1953-1963	5.4	9.0	0.6
N. W. England		**PAHs**	1899	1952	1948-1968	4.3	10.8	0.4
Core E-30,	May, 1990	**PCBs**	1925	1969	1961-1969	20.8	69.3	0.3
L. Ontario,		**PAHs**	ND	1949	1945-1949	-	-	0.3
USA/Canada								
Core G-32,	May, 1990	**PCBs**	1927	1970	1966-1970	9.6	24.0	0.4
L. Ontario,		**PAHs**	ND	1948	1943-1952	-	-	0.3
USA/Canada								

a Duration period of maximum inputs.

ND Background levels of PAHs not determined since Lake Ontario cores did not extend to sufficient depth.

Lake Ontario E-30 and G-32 are 5.0, 46 and 42 times greater than inputs to Loch Ness (Sanders *et al.*, 1992; Sanders, 1993). Lake Ontario, however, is an example of a polluted watershed, whereas Esthwaite Water is a shallow semi-rural lake which receives limited quantities of treated sewage. Fluxes of PAHs are also considerably lower to Loch Ness sediment than the other examples cited. Esthwaite Water, Lake Ontario E-30 and G-32 sediment cores received 15, 4.0 and 3.0 times greater fluxes of PAH, respectively, during maximum input (Sanders *et al.*, 1993; Sanders, 1993). It should be noted, however, that some inter-core differences exist in the number of PCB congeners and PAH compounds quantified in the various studies.

Possible Disturbances to the Sediment Record

Physical processes continually at work within sediments can lead to a gradual alteration, and possible disturbance, of the accumulating stratigraphy. Such mechanisms eventually result in partial loss of temporal resolution within the core, or in the case of very slowly accumulating sediments, complete destruction of the historical record. As such, contaminant profiles in all sediment cores are distorted to varying degrees.

Physical mixing of bottom sediment can be particularly detrimental when carrying out historical monitoring. Resuspension of surface sediment via water turbulence and fetch are highly unlikely to create any disturbance at the 210 m depth from where the core was obtained. Reworking of bottom sediment by benthos and burrowing organisms (e.g. oligochaete worms) is, however, likely to be of significance. Sub-surface burrowing by 'conveyer-belt' feeders will result in the movement of particulate matter, and hence will mix those substances bound to the solid phase. The population of benthos, and rate of sedimentation, will regulate the specific impact of bioturbation, and thus govern the potential degree of historical record disruption. Molecular diffusion of chemicals through the aqueous phase will supplement the mixing effect. This process is primarily dependent upon the aqueous solubility of the chemical, and may also be influenced by the levels of dissolved organic carbon in the sediment pore water.

It is also important to consider the fate of a compound following deposition to a water surface, and the potential losses incurred during its passage through the water column and after incorporation into the sediment profile. For example, biotic and abiotic degradation may serve to deplete certain susceptible compounds, and enhance levels of the more recalcitrant components. It is therefore important to acknowledge that historical sediment records do not quantifiably reflect inputs to a water body, but rather provide an overall qualitative time-trend assessment of

the remaining resistant component. Sediment trap studies, for example, have suggested that typically <10% of the PCB fraction entering the water column becomes incorporated into the bottom sediment (Sanders, 1993). A large proportion of the remainder is returned to the atmosphere following outgassing across the water/air surface.

Sources of PCBs and PAHs to Loch Ness

The catchment area of Loch Ness is vast, covering an approximate area of 1,775 km^2 (Maitland, 1981). The Foyers system drains the east side of the loch, while the significantly larger Moriston, Caledonian (Oich and Garry) and Enrick catchments drain from the west. Establishing specific contaminant source functions is therefore particularly complex, and is not attempted in this paper. It is, however, pertinent to suggest potential modes of contaminant supply to the loch and its catchment, and broadly to discuss their potential impact on the region.

Potentially significant point sources of PCBs are likely to be small in number, and at worst would be restricted to leakages from dispersed transformer units. PAHs are likely to be delivered to the catchment from many small point sources, e.g. residential burning of coal and wood. The significance of these emissions in such a sparsely populated area is difficult to predict. Heather and stubble burning would also add to environmental burdens of PAHs. Just how widespread these methods are practised within the catchment is not known. Emissions from motor vehicles traversing lochside routes, and motor boats passing through the loch itself, are examples of mobile sources which may play an important role in the supply of PAHs. Seasonal increases in tourist traffic are likely to have a significant bearing on the importance of this source.

Atmospheric deposition may be of great consequence as a source of pollution to this relatively rural and non-industrialised region. PCBs and PAHs in the gaseous phase or particulate-bound solid phase may be transported hundreds or even thousands of miles in the upper atmosphere from areas of high level contamination, and then be deposited onto areas of low contamination. Atmospherically derived sources to the Central Highland region may originate from industrial and urban conurbations elsewhere in Britain through northerly wind directions. In addition, prevailing westerly winds may deliver pollutant packages from North America, and occasional east winds will transport contaminated aerosols from the industrial heartlands of Central Europe. Particle-rainout has been reported to be the dominant deposition process (Ballschmitter, 1991), and will be of particular significance in this area of relatively high rainfall. Dry-

deposition (gravity) is less significant, but is nevertheless an important atmospheric contaminant removal mechanism. Particle-bound contaminants will be washed into streams and rivers, eventually find their way downstream, and so ultimately enter the loch. Flood events will be particularly important in delivering large masses of suspended particulate material to terminal water bodies, and may result in a subsequent increase in pollutant fluxes.

General Comments

This short paper has attempted to interpret concentration/depth data, derived from a dated lacustrine sediment core, for both PCBs and PAHs - two groups of compounds whose environmental presence, persistence, and potential toxicological effects are currently being viewed with concern. The historical record preserved within the core has been discussed in general terms, and in relation to production, usage and source functions. The advantages, disadvantages and realisticity of employing retrospective assessment techniques have been discussed. Despite some slight ambiguity in the present data, the Loch Ness core corroborates the findings of other sediment studies, both national and international. It also helps to form a broader picture of PCB and PAH loadings in the U.K. environment, both historical and spatial.

Acknowledgements

The authors would like to express their thanks to the following for assistance during the course of this work: the Natural Environment Research Council for funding, under grant number GT4/89/AAPS/28; Dr. Mike Kelly, University of Lancaster, for determing Cs activities; Mr. John Minshull, skipper of the RV *Ecos*; and Mr. Mungo Sanders for helpful advice.

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Received May 1993

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THE PROFUNDAL FAUNA OF LOCH NESS AND LOCH MORAR

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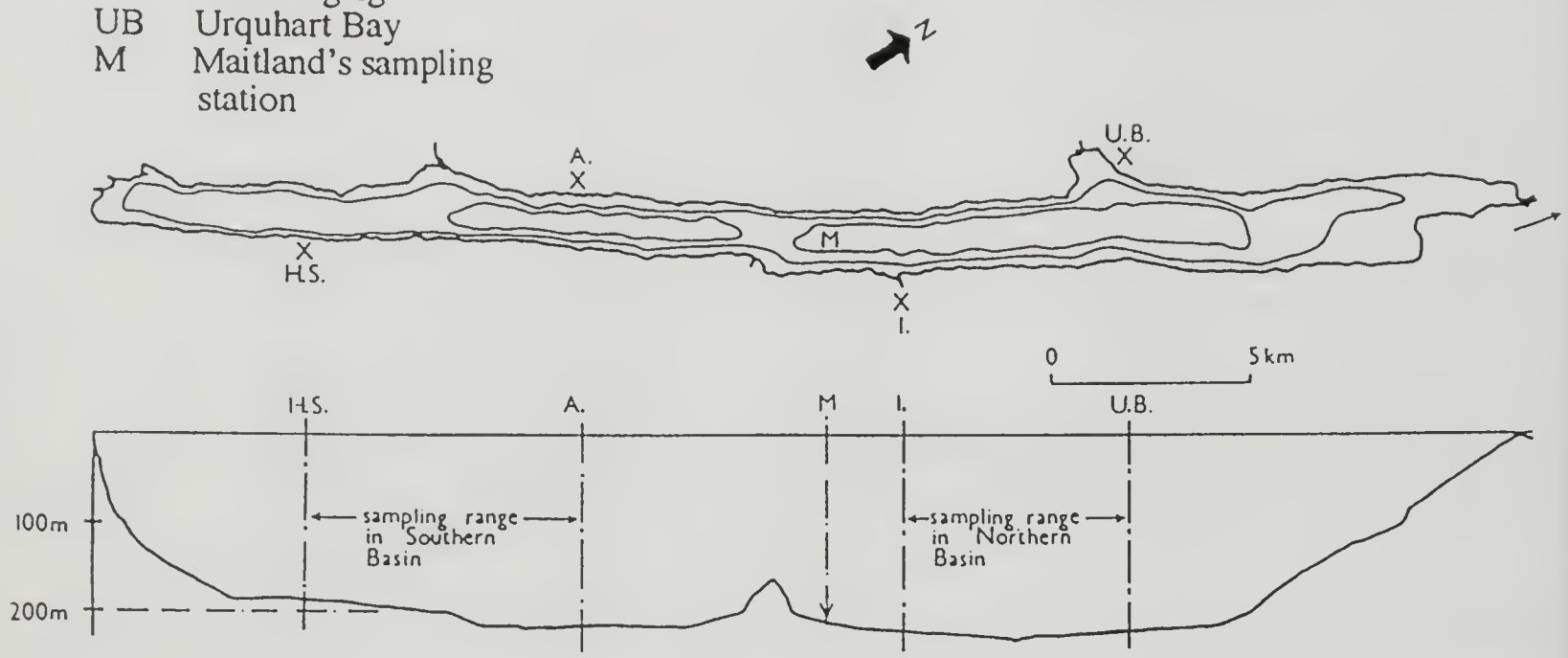
Introduction

The importance and biological interest of the profundal faunas of Loch Ness (230 m) and Loch Morar (310 m) is that they inhabit depths greater than 200 m or 300 m, which are deep on a world scale. The profundal sediments are also very extensive, occupying over 50% of the area of Loch Ness greater than 150 m deep (Smith, Cuttle and Maitland, 1981) and 27% greater than 200 m deep; the corresponding percentages for Loch Morar are 28% and 19% (Mr. D.S. Martin, pers. comm.). After the early studies instigated by Sir John Murray (Murray, 1904 and 1908; Murray and Pullar, 1910), few authors published on the fauna inhabiting the deep sediments of Loch Ness or Loch Morar until Maitland (1981), Shine and Martin (1988), and Griffiths, Martin, Shine and Evans (1993). Little work was done on the profundal fauna of five Scottish lochs during the 1977-80 survey (Maitland, 1981) but Smith *et al.* (1981) reviewed what had been recorded earlier. Dredgings from 90-230 m depths in Loch Ness by Murray and Pullar collected the bivalve *Pisidium*, subsequently identified as *P. conventus* and *P. personatum*, the lumbriculid *Stylodrilus heringianus,* and *Chironomus* sp., together with the 'casual' occurrence of *Hydra* and *Lymnaea peregra* from depths of 120-180 m. Samples taken from c. 200 m depth in Loch Morar contained two lumbriculid worms, *Lumbriculus variegatus* and *Stylodrilus heringianus* (Smith *et. al.*, 1981).

These authors also recorded that the profundal sediments of Loch Ness, taken by core, consisted of fine size fractions with clay (<39 μm, 45.8%), fine silt (39-63 μm, 18.1%) and sand (63-125 μm, 35.4%), low organic content (loss on ignition, 8.9%) and a pH of 5.4. The paucity of records is largely due to the difficulties of sampling sediments at the great depths of these lochs. As part of the sampling

LOCH NESS
HS Horseshoe Scree
A Alltsigh
L Inverfarigaig
UB Urquhart Bay
M Maitland's sampling station



LOCH MORAR
S Swordlands
ME Meoble
P LNMP sampling area
M Maitland's sampling station

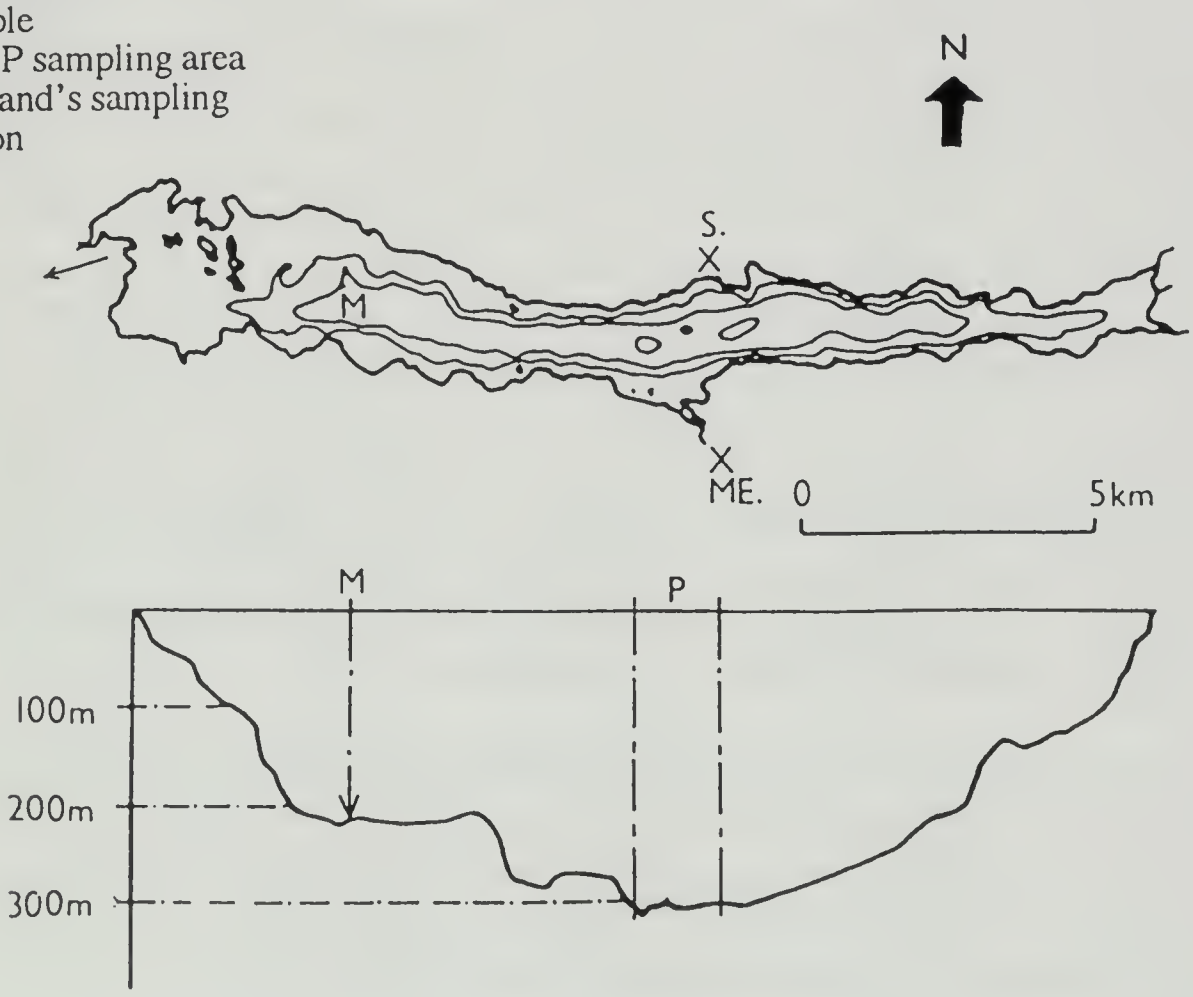


Figure 1

Outline maps and depth profiles of Loch Ness and Loch Morar, showing sampling sites.

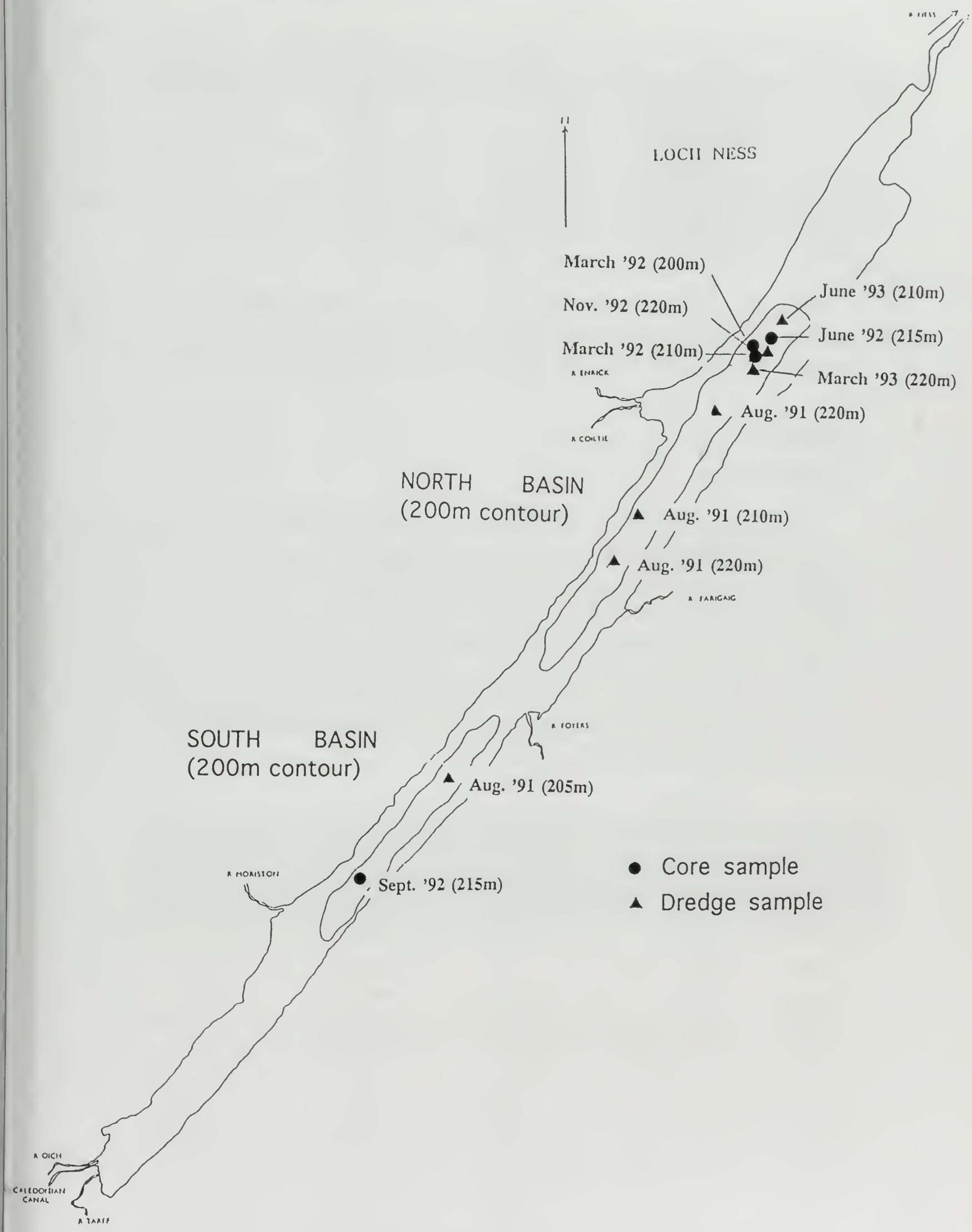


Figure 2

Outline map of Loch Ness, showing 200 m depth contour, and position, depth and date of core and dredge samples from the profundal sediments during 1991-93.

programme undertaken by the Loch Ness and Morar Project, Shine and Martin (1988) designed a variety of collecting techniques, and compiled a list, not previously published, of thirty profundal zoobenthic species, at an average density of 295 individuals/m², from Loch Ness. Ostracods formed an important component, comprising over 60% of the fauna by numbers. The four species recorded from the deep sediments (>200 m) of Loch Ness were *Candona angulata* G.W. Müller, *C. candida* (O.F. Müller), *Cryptocandona reducta* (Alm) and *Cypria ophthalmica* (Jurine) (Griffiths *et al.*, 1993).

This present paper publishes the full listing of macrobenthic and meiofaunal species from the profundal sediments of both lochs, collected over the past ten years during the Loch Ness and Morar Project's benthic sampling programme.

Methods

Sampling Sites

The samples from Loch Ness were mostly collected between June and October of 1982-85, from mid-loch and in depths between 189 and 230 m, from the areas Horseshoe Scree to Alltsigh and between Inverfarigaig to Urquhart Bay (Figure 1). The profundal sites (>200 m) sampled during 1991-93 are plotted in Figure 2. Samples from Loch Morar, collected during July or August in 1978-80 and 1985, were all taken from depths of 295-310 m in the deep basin between Meoble Bay and Swordlands (Figure 1). Echo-sounders were used to measure the depths being sampled, as well as to detect and control the descent of the sampling gear *in situ*, especially the Ekman sampler (Figure 3).

Collecting Gear

In the absence of the expensive Jenkins mud-sampler, several techniques were used to collect samples from the deep sediments during the earlier sampling period (1978-85) (Figures 4 and 5). Unquantitative samples were taken in both lochs, using a weighted dredge with a fine mesh cod-end which collected the larger organisms; additional unquantitative methods, used only in Loch Ness, were fine-meshed eel-traps on the loch bottom and a set of gill nets of 50 mm mesh (1.4 m high and 125 m long) kept suspended with the lead-line resting on the sediments. Left overnight, these caught profundal fish and some invertebrates. Quantitative samples were mostly taken by a weighted Ekman grab (15 cm x 15 cm) or, in Loch Morar only, by a 5.0-litre brass Patalas volume sampler, which sampled an area 10 cm x 10 cm in the deep basin of 295-310 m depth. Two special bottom samplers

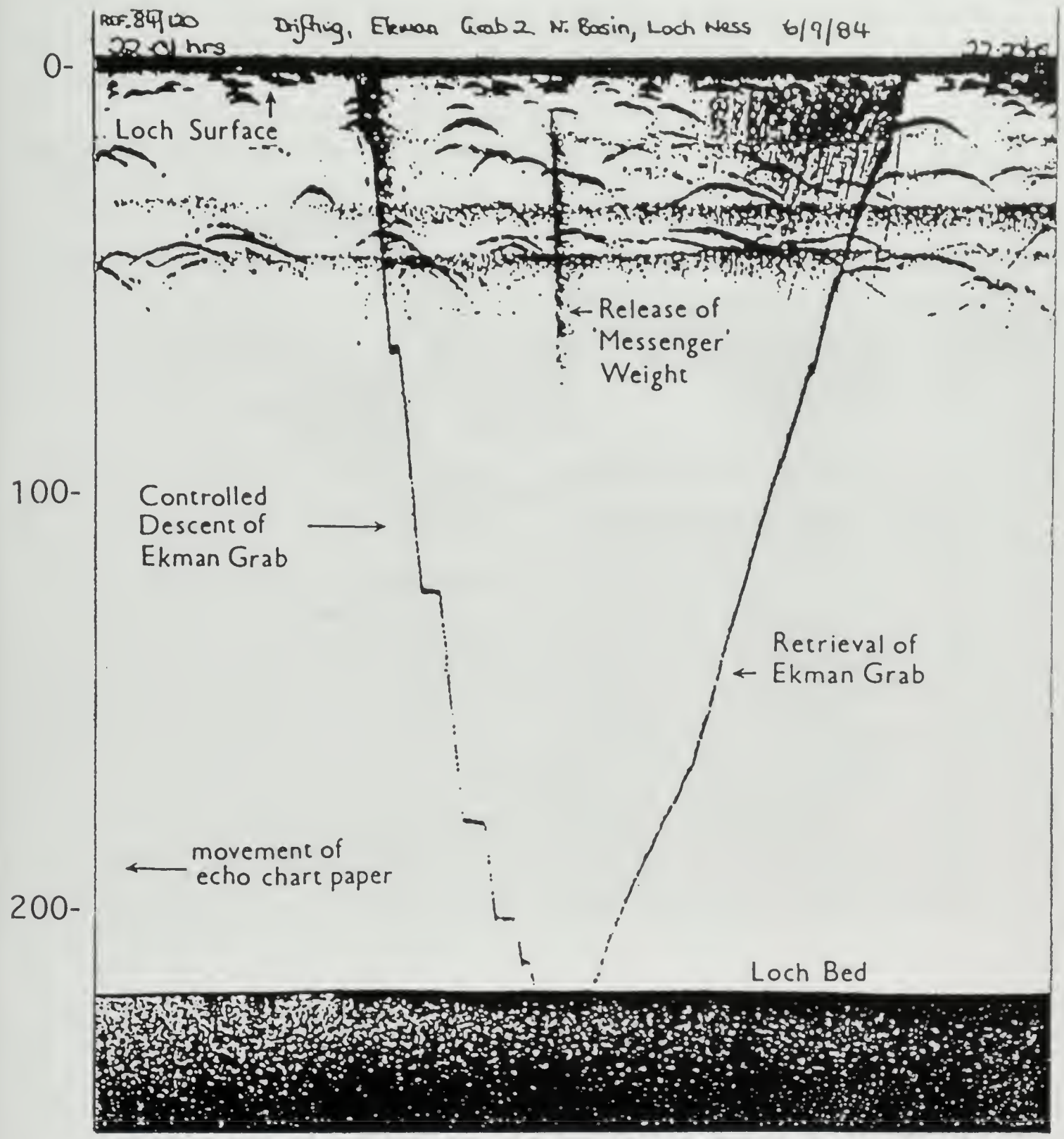


Figure 3

The descent of the Ekman Grab sampler controlled by echo-sounder.

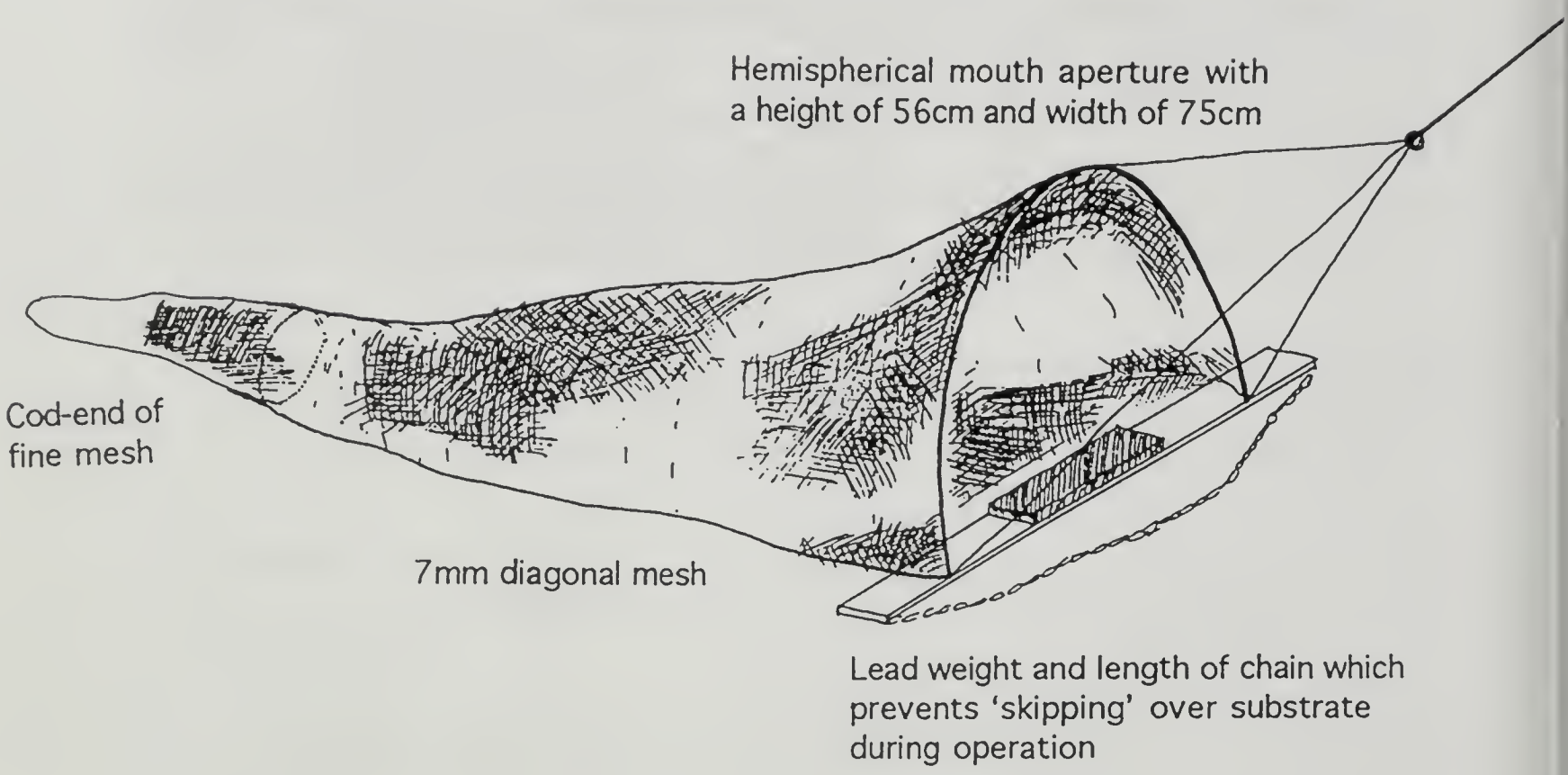

Hemispherical mouth aperture with
a height of 56cm and width of 75cm
Cod-end of
fine mesh
7mm diagonal mesh
Lead weight and length of chain which
prevents 'skipping' over substrate
during operation

Figure 4

The Loch Ness and Morar Project dredge sampler.

(Figure 5) were designed by Adrian Shine to collect the surface few centimetres of sediment: a 0.25 m^2 scoop bottom sampler, and a 0.25 m^2 quadrat bottom sampler. Their deployment is illustrated in Figure 5.

More recent sampling in Loch Ness (1991-93) was conducted using a new quantitative 10.3 cm diameter corer (Figure 6), which permitted sub-samples to be cut at 1.0 cm intervals, thus giving samples of 83.3 cm^3 for each 1.0 cm depth interval. A second technique used was to dredge the sediment surface. In Loch Morar during the 1990s, only the deep basin (310 m) was sampled, by leaving a buoyed sterilised hessian sack on the bottom and retrieving it after two weeks.

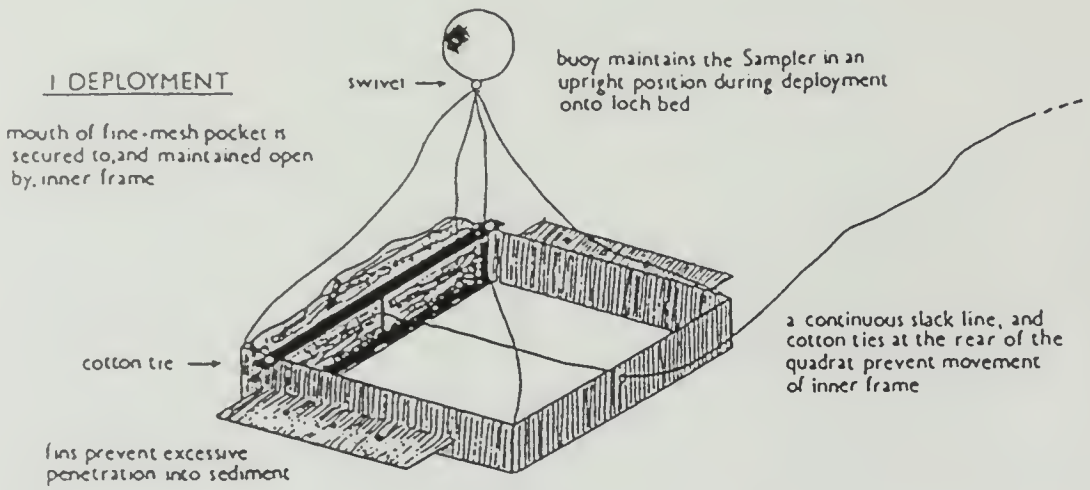
Sample Treatment

Profundal samples were kept alive in a refrigerator, seived, and sorted live as soon as possible; samples for fine-sorting in London were transported overnight in a cold container. Some chironomids were kept alive until they emerged as adults. Only Loch Morar sediment samples were washed through a series of seives down to 75 μm mesh. The most effective method of quantitative sorting of the Loch Ness quantitative samples was by visually panning a series of diluted 10 ml sub-samples until the whole sample was completed. This was continued until no more live animals were detected. Sorted animals were preserved and sent to taxonomic specialists for identification (Tables 1 and 2). The 1990s Loch Ness samples from the corer were mostly cut into slices, 0.0 - 1.0 and 1.0 - 2.0 cm from the surface mud, and totally sorted. The whole mud sub-sample was examined microscopically, one spatula load at a time, and diluted to the thinnest layer possible in a petri dish. The surface dredge samples were seived through 100 μm mesh after settlement of larger particles.

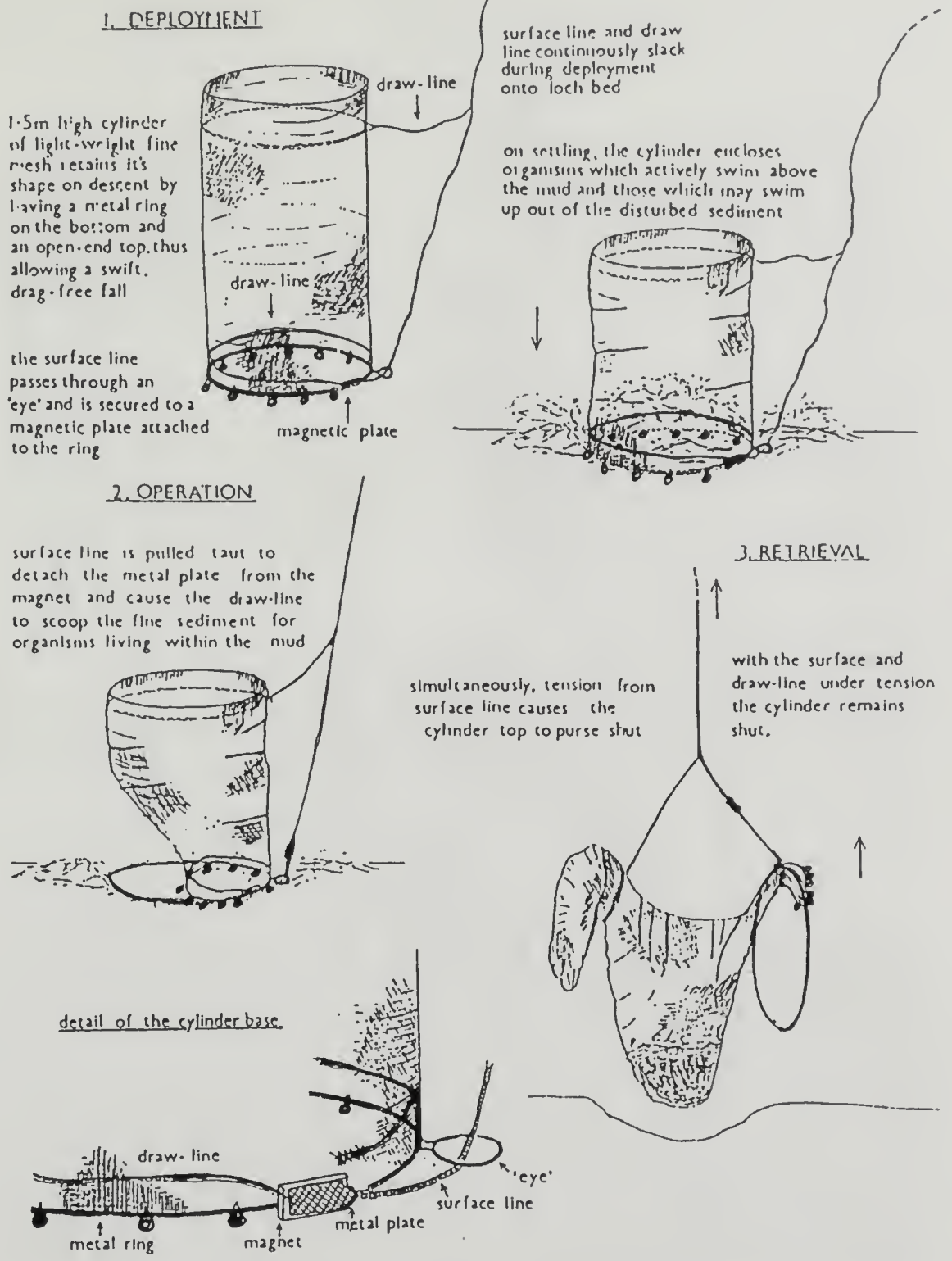
The Loch Ness records for the period 1982-85 came from a total of 37 samples (eight by dredging, six by the scoop or quadrat samplers, and 23 by Ekman sampler) and for the 1991-93 period from a total of 11 samples (seven by dredging and four by coring); the Loch Morar records for 1978-85 came from a total of 12 samples (eight by Patalas sampler, three by Ekman sampler, and one by dredging).

Results

Twenty-nine species or genera of profundal invertebrates, and two species of fish, were recorded in Loch Ness during the earlier period of sampling, compared with only seventeen species or genera of invertebrates in Loch Morar (Table 1). The lesser number of species recorded in Loch Morar reflects the smaller sampling


1. DEPLOYMENT
swivel
buoy maintains the Sampler in an upright position during deployment onto loch bed
mouth of fine-mesh pocket is secured to, and maintained open by, inner frame
a continuous slack line, and cotton ties at the rear of the quadrat prevent movement of inner frame
cotton tie
fins prevent excessive penetration into sediment
2. OPERATION
hauling the line breaks the cotton ties, and pulls the inner frame across the quadrat, to secure the sediment within the pocket
3. RETRIEVAL
inner frame lies flush against the quadrat, retaining the sediment sample

THE SHINE BOTTOM SAMPLER
(collects 0·25 m² of sediment)


1. DEPLOYMENT
draw-line
1·5m high cylinder of light-weight fine mesh retains it's shape on descent by having a metal ring on the bottom and an open-end top, thus allowing a swift, drag-free fall
surface line and draw line continuously slack during deployment onto loch bed
on settling, the cylinder encloses organisms which actively swim above the mud and those which may swim up out of the disturbed sediment
draw-line
the surface line passes through an 'eye' and is secured to a magnetic plate attached to the ring
magnetic plate
2. OPERATION
surface line is pulled taut to detach the metal plate from the magnet and cause the draw-line to scoop the fine sediment for organisms living within the mud
3. RETRIEVAL
simultaneously, tension from surface line causes the cylinder top to purse shut
with the surface and draw-line under tension the cylinder remains shut.
detail of the cylinder base.
draw-line
'eye'
surface line
metal plate
metal ring
magnet

THE LNMP SCOOP BOTTOM SAMPLER

Figure 5a: THE SHINE BOTTOM SAMPLER

Deployment:

Mouth of fine-mesh pocket is secured to, and maintained open by, inner frame.

Fins prevent excessive penetration into sediment.

Buoy maintains the Sampler in an upright position during deployment on to loch bed.

A continuous slack line, and cotton ties at the rear of the quadrat, prevent movement of inner frame.

Operation:

Hauling the line breaks the cotton ties, and pulls the inner frame across the quadrat, to secure the sediment within the pocket.

Retrieval:

Inner frame lies flush against the quadrat, retaining the sediment sample.

Figure 5b: THE L.N.M.P. SCOOP BOTTOM SAMPLER

Deployment:

1.5 m high cylinder of light-weight fine mesh retains its shape on descent by having a metal ring on the bottom and an open-end top, thus allowing a swift, drag-free fall.

The surface-line passes through an 'eye', and is secured to a magnetic plate attached to the ring.

Surface-line and draw-line are continuously slack during deployment on to loch bed.

On settling, the cylinder encloses the organisms which actively swim above the mud, and those organisms which may swim up out of the disturbed sediment.

Operation:

Surface-line is pulled taut to detach the metal plate from the magnet, and to cause the draw-line to scoop the fine sediment for organisms living within the mud.

Simultaneously, tension from surface-line causes the cylinder top to purse-shut.

Retrieval:

With the surface-line and draw-line under tension, the cylinder remains shut.

Figure 6

The Project's wide-bore sediment coring system has also proved effective for quantitative benthos collection

effort, and the fewer collecting techniques employed, rather than implying any real difference. The species came from ≥200 m depth. Benthic collections were made at other depths, but are excluded from this paper. In Table 1, most of the species collected were the larger macrobenthic forms present, due to the methods of collection. That these methods did collect the small ostracods and copepods probably reflects their numerical abundance. Some collecting methods turned out to be selective; for example, the scoop sampler (Figure 5) was better at catching cyclopoid copepods, which swim just above the sediments, than the Ekman sampler.

Table 2 lists the species collected during the more recent sampling series (1991-93), using better methods of collection (e.g. a corer), with smaller volumes of mud, more easily sorted accurately and quantitatively. This list includes additional species/genera recorded, and also contains more of the smaller meiobenthic groups of animals which are more difficult to extract from the mud. This brings the total for Loch Ness to sixty-four invertebrate species/genera, plus two fish species, and for Loch Morar to thirty six species/genera. These lists are based on extracting whole live specimens.

Further species were later added to the list, by accepting the chironomid head capsules sorted from the top few cms of Loch Ness core samples. These further species were identified by Mr. D.P. Gallagher as follows: *Heterotrissocladius, Orthocladius, Synorthocladius, Paratrichocladius, Psectrocladius, Pseudochironomus* and *Tanytarsus.*

Comparing the two lochs, twenty-one species or genera were recorded in both lochs. With more frequent and more extensive sampling, it seems likely that the number of species recorded from Loch Morar will increase. In Loch Lomond, the only other major Scottish loch in which the profundal benthos has been sampled, only nine species (four oligochaete, two of *Pisidium,* and three chironomid species) were recorded (Weerekoon, 1956; Slack, 1965; Maitland, 1981).

Discussion

Under the stable environmental conditions of the profundal (≥200 m) of Loch Ness, i.e. constant cold (5.6°C), darkness, high levels of dissolved oxygen (>80% saturated), low conductivity (<100 $uS.cm^{-1}$) and great hydrostatic pressure (Shine and Martin, 1988), a fauna of surprising diversity exists, which can be sub-divided as follows:

(A) The true profundal macrobenthic groups of chironomids (with 13 species/genera), oligochaetes (14 species) and the sphaeriid bivalve *Pisidium* (four species), each containing a dominant species within their group.

(B) The true profundal meiobenthic groups of the ostracods (six species), the nematodes (five species), harpacticoid copepods (three species) and cyclopoid copepods (two species), each contributing dominant species within their group.

(C) A series of macrobenthic groups, comprising turbellarians (two species), isopods (two species), amphipods (one species), and Trichoptera (three species); and meiobenthic groups, comprising protozoans (five species), microturbellarians (one species), rotifers (two species), tardigrades (one species), and oribateids (one species), with fewer representatives and whose distribution is not characteristically profundal. The chydorid cladocerans (seven species) have also been placed in this group, for reasons given below.

(D) The two fish species, i.e. Lamprey *Lampetra* sp. and Charr.

Apart from the fish, these organisms are all living on or in the sediments, or in the water just above the sediments of very fine fraction (Smith *et al.*, 1981), and with an organic content which ranges between 18.29% at Inverfarigaig at 210 m to 33.9% at Invermoriston at 210 m (Mr. J.D. Hamilton, pers. comm.). The new values are higher than the 8.9% organic content recorded by Smith *et al.* (1981), which came from a single core taken in the less deep shoulder of Loch Ness between the North and South Basins where the loch is under the influence of the River Foyers (Figure 2). In the profundal, most of the listed species will be detritivorous, apart from the carnivorous groups like the turbellarians, cyclopoid copepods, tanypodine chironomids and fish.

Sub-division (A)

The chironomids, oligochaetes and species of *Pisidium* belonging to sub-division (A) contribute species to the profundal macrobenthos in some other deep, oligotrophic lakes of Europe, e.g. Lake Malaren (Ahren and Grimas, 1965), Thingvallavatn (Lindegaard, 1992), Lago Maggiore (Lenz, 1954; Della Croce, 1955; Stella, 1964; Bonomi, 1967; Kuiper, 1981), Lago di Mergozzo (Bonomi and Ruggin, 1966), and Lake Geneva (Zschokke, 1911; Juget, 1958; Dussart, 1967); and of North America, e.g. Great Slave Lake (Rawson, 1953), and the St. Lawrence Great Lakes (Cook and Johnson, 1974).

Sub-division (B)

Similarly, the sub-division (B) groups contribute to the profundal meiobenthos in Finnish lakes, e.g. Paajarvi (Holopainen and Paasivirta, 1977) and Paijanne (Sarkka, 1992); in Polish lakes (Prejs and Papinska, 1983); and in pre-alpine Austrian lakes, e.g. Vorderer Finstertaler See (Bretschko, 1973, 1975, 1984), Piburger See (Pehofer, 1977) and Mondsee (Danielopol *et al.*, 1988).

Sub-division (C)

Sub-division (C) is very heterogeneous, and consists of species able to survive in the profundal zone but not especially characteristic of it. For example, nine of Fryer's (1985) list of crustacean species, collected more from large rather than small water bodies in his survey of 207 lowland Yorkshire waters, are recorded in Loch Ness or Loch Morar: of these, four are chydorid cladocerans (*Alona affinis, Chydorus sphaericus, Eurycercus lamellatus* and *Acroperus harpae*), plus the ostracods *Cyclocypris ovum* and *Cypria ophthalmica,* the cyclopoids *Paracyclops fimbriatus* and *Megacyclops viridis,* and the isopod *Asellus aquaticus.* These might be termed vagile (widely dispersive) organisms. Some of sub-division (C) are introduced species: *Phagocata woodworthi* (turbellarian) (Reynoldson, Smith and Maitland, 1981) and *Crangonyx pseudogracilis* from North America. The presence of *Asellus* spp. in the profundal is less surprising when one considers how the amphipod *Pontoporeia affinis* dominates the deep profundal benthos of the St. Lawrence Great Lakes (Cook and Johnson, 1974) and the Great Slave Lake (Rawson, 1953) in North America, although to a greater extent than seems to occur in European lakes. The Trichoptera larvae (and Plecoptera nymphs in Loch Morar) are probably littoral in origin, but are able to survive in the well-oxygenated profundal sediment surface. However, in the few biological studies of the deep sediments of oligotrophic lakes which include the profundal meiobenthos, species are recorded in the profundal which belong to the same animal groups listed in sub-division (C), plus some others (Holopainen and Paasivirta, 1977). Many of the sub-division (C) species are rare or exist as sparse populations able to survive under the stable environmental conditions of Loch Ness deep sediments (Giller, 1984).

Sub-division (D)

The Lamprey was a larva and was caught by the hessian sack technique. More information on the numbers and sizes of profundal Charr caught can be found in Shine and Martin (1988) and Shine, Kubecka, Martin and Duncan (1993).

More detailed accounts of the seven groups in sub-division (A) and sub-division (B), i.e. Chironomidae, Oligochaeta, Sphaeriidae, Ostracoda, Nematoda, Harpacticoid Copepoda, and Cyclopoid Copepoda, are as undernoted:

Chironomidae

The taxonomic composition of the profundal Chironomidae was more diverse in Loch Morar than in Loch Ness, despite the fewer species collected. The Loch Ness forms belonged to only two sub-families, the Tanypodinae (six taxa), with predacious head capsules and capable of feeding on small invertebrates, and the Chironominae (six taxa), with a non-carnivorous head capsule, a variety of feeding habits and diets, and capable of producing haemoglobin and silken threads for tube-building (Bryce and Hobart, 1972).

Among the Loch Morar taxa, one was tanypodine, three were chironomine, and two belonged to the Orthocladiinae, another non-carnivorous sub-family capable of producing silk but not haemogloblin (that is, without preadaptation to low oxygen conditions). In Loch Ness the two most numerous species were the chironomine *Sergentia coracina* and the tanypodine *Procladius* spp., and in Loch Morar *Sergentia* spp. were dominant. The presence of the orthocladine *Heterotrissocladius grimshawi* and tanytarsine *Stempellinella* spp. in Loch Morar suggests a greater degree of oligotrophy than in Loch Ness (Cook and Johnson, 1974; Lindegaard, 1992).

Oligochaeta

In both lochs, three families of oligochaetes were represented: Naididae (*Specaria josinae* - Lake Paijann; Sarkka, 1992), Tubificidae (*Spirosperma ferox* and *Tubifex tubifex* - Thingvallavatn; Lindgaard, 1992), and Lumbriculidae (*Stylodrilus heringianus* and *Lumbriculus variegatus* - Thingvallavatn; Lindegaard, 1992), in each case with characteristic deep-water profundal species (indicated in brackets) recorded in similar circumstances elsewhere. In the oligotrophic Finnish Lake Paijanne (Sarkka, 1992), a higher proportion of naidid over tubificid species indicated a greater degree of oligotrophy compared with eutrophicated areas of the lake. The most abundant oligochaete species was the tubificid *Spirosperma ferox* in Loch Ness, and *S. velutinus* in Loch Morar.

Sphaeriidae

According to Odhner (1923) and Kuiper (1974), *Pisidium conventus* is an arctic species which survives in the cold regions of alpine and deep temperate

lakes. In Loch Morar it was the only species collected, and of the four species in Loch Ness, it was the most abundant species, together with *P. personatum.*

Ostracoda

This was the most abundant group collected in both lochs. Of the four species recorded in Loch Morar, *Cyclocypris ovum* and *Cypria ophthalmica* are listed by Fryer (1985) as crustacean species showing a preference for large water bodies. *Candona candida* and *Cryptocandona reducta,* present in both lochs, were less common in Loch Ness than *Cypria ophthalmica* and *Candona angulata* (Griffiths *et al.,* 1993), who comment upon the low ostracod species diversity they found. Danielopol *et al.,* (1985, 1988) recorded as many as nine species of ostracods in the profundal of Mondsee, Austria, two species of which occur in Loch Ness, *Candona candida* and *C. neglecta* (Table 1).

Nematoda

The nematodes listed in Table 2 are the commoner species collected from the profundal sediments of Loch Ness ≥200 m where they attained densities of up to 10,000 individuals/m^2 (Mr. D.S. Martin, pers. comm.). It is not an exhaustive list, and more species (*Eumonhystera filiformis* group, *Eumonhystera* cf. *longicaudatula, Ethmolaimus pratensis* group, *Aphanolaimus* sp. and *Dorylaimus* cf. *stagnalis*) and greater densities (particularly of *Ironus tenuicaudatus,* with densities of up to 20,000 individuals/m^2) are found in lesser depths such as 50-170 m (Dr. F. Schiemer, pers. comm.). The species listed consist of widely distributed nematode species known from a wide range of habitats, such as ponds, rivers, and especially lakes, but together these species form a nematode association characteristic of the profundal zone of deep oligotrophic lakes with fine sediments, low food availability and good oxygen conditions.

Such nematode associations, with different species missing depending upon particular local conditions, have been found in the Austrian alpine and pre-alpine lakes, such as Vorderer Finstertaler See (Bretschko, 1984), Attersee (Dudinski, 1979), and Piburger See (Pehofer, 1977); in Polish alpine lakes (Prejs, 1977b); in the Finnish oligotrophic Lake Paajarvi (Holopainen and Paasivirta, 1977); and in the arctic Lake Char (Prejs, 1977a). It seems that the species composition of profundal nematodes, and the carrying capacity of the sediments, are influenced less by interspecific competition and more by the combined influence of the nature of the sediments, the degree of oxygenation and the level of food available (Dr. F. Schiemer, pers. comm.).

Table 1

SPECIES RECORDED IN THE PROFUNDAL FAUNAS OF LOCH NESS (≥ 200m) AND LOCH MORAR (≥ 300m) DURING 1978-85

Group	Species or Genus	Loch Ness	Loch Morar	Iden By
Turbellaria	*Phagocata vitta* (Duges, 1830)	*	–	Ma
	Phagocata woodworthi Hyman, 1937	*	–	Wr
Nematoda	*Mononchus* spp. Bastian, 1865	–	*	Sc
Oligochaeta	*Homochaeta naidina* Bretscher, 1896	–	*	Si
	Tubifex tubifex (Müller, 1774)	*	*	La
	Spirosperma ferox (Eisen, 1879)	*	–	La
	Spirosperma velutinus (Grube, 1879)	–	*	Si
	Lumbriculus variegatus (Müller, 1774)	*	*	La
	Stylodrilus heringianus Claparede, 1862	–	*	Si
Bivalvia	*Pisidium casertanum* (Poli, 1791)	*	–	Ba
	Pisidium conventus Clessin, 1877	*	*	Ba,K,
	Pisidium personatum Malm, 1855	*	–	Ba
	Pisidium lilljeborgii Clessin, 1886	*	–	Ba
Ostracoda	*Candona angulata* G.W. Müller, 1900	*	–	H
	Candona candida (O.F. Müller, 1785)	*	–	H
	Candona neglecta Sars, 1887	*	–	H
	Cryptocandona reducta Alm, 1914	*	–	H
	Cyclocypris ovum (Jurine, 1820)	–	*	Lo
	Cyclocypris spp. Kaufmann, 1900	*	–	H
	Cypria ophthalmica (Jurine, 1820)	*	–	H
Copepoda	*Echinocamptus echinatus* (Mrazek,1893)	–	*	Bo
	Paracyclops fimbriatus (Fischer, 1853)	–	*	Bo
	Megacyclops viridis (Jurine, 1820)	*	–	Bo
	Acanthocyclops nanus (Sars, 1863)	–	*	Bo
	Cyclops spp. O.F. Müller, 1776	–	*	Bo
Malacostraca	*Asellus aquaticus* (Linnaeus, 1758)	*	–	E
	Asellus meridianus Racovitza, 1919	*	–	E
	Crangonyx pseudogracilis Bousfield,1958	*	–	E,F

Table 1

SPECIES RECORDED IN THE PROFUNDAL FAUNAS OF LOCH NESS (≥ 200m) AND LOCH MORAR (≥ 300m) DURING 1978-85

Group	Species or Genus	Loch Ness	Loch Morar	Ident. By
Trichoptera	*Plectrocnemia conspersa* (Curtis,1834)	*	–	A
	Polycentropus flavomaculatus (Pictet,1834)	*	–	A
	Holocentropus dubius (Rambur, 1842)	*	–	A
Chironomidae	*Procladius crassinervis*(?) (Zetterstedt,1838)	*	–	C
	Procladius spp. Skuse, 1889	*	–	C,P
	Arctopelopia spp. Fittkau, 1962	*	–	P
	Heterotrissocladius grimshawi(?) (Edwards,1929)	–	*	C
	Limnophyes spp. Eaton 1875	–	*	C
	Paracladopelma nigritula(?) (Goetghebuer, 1942)	*	–	C
	Paracladopelma spp. Harnisch, 1923	*	–	C
	Phaenopsectra flavipes (Meigen, 1818)	–	*	C
	Sergentia coracina (Zetterstedt, 1850)	*	–	C,P
	Sergentia spp. Keiffer, 1921	*	*	C
	Stempellinella spp. Brundin, 1947	–	*	C
Fish	*Lampetra fluviatilis*(?) (Linnaeus, 1758)	*	–	Wh
	Salvelinus alpinus (Linnaeus, 1758)	*	–	G,Ma

Key: * recorded – not recorded

A - P.C. Barnard	G - R.B. Greer	Mo - P. Mordan
Ba - J.A. Bass	H - P.A. Henderson	P - L.C.V. Pinder
Bo - G.A. Boxshall	K - M.P. Kerney	Sc - F. Schiemer
C - P.C. Cranston	La - M. Ladle	Si - R.W. Sims
E - J.P. Ellis	Lo - H. Löffler	Wh - A.C. Wheeler
F - G. Fryer	Ma - D.S. Martin	Wr - J.F. Wright

Table 2

ADDITIONAL SPECIES RECORDED IN THE PROFUNDAL FAUNAS OF LOCH NESS (≥200m) AND LOCH MORAR (≥300m) DURING 1991-93

Group	Species or Genus	Loch Ness	Loch Morar	Ident. By
Ciliophora	*Paramecium* 'type'	*	–	M
Rhizopoda	*Arcella* sp.	*	*	M
	Centropyxis sp.	*	*	M
	Difflugia sp.	*	*	M
	Nebela sp.	*	*	M
Microturbellaria		*	*	M
Turbellaria		–	*	M
Rotifera	*Habrotrocha bdelloid*	*	–	P
	Non-*Habrotrocha bdelloid*	*	–	P
Nematoda	*Ironus tenuicaudatus* de Man	*	–	S
	Tripyla glomerans grp.	*	*	S
	Tobrilus gracilis grp.	*	–	S
	Tobrilus cf. *pellucidus*	*	–	S
	Dorylaimid 'A'	*	–	S
	Mononchus cf. *macrostoma*	–	*	S
Oligochaeta	*Chaetogaster diastrophus* (Gr.)	*	–	Bi
	Nais variabilis Piquet	–	*	Bi
	Specaria josinae (Vejdovsky)	*	–	Bi
	Tubifex/Potamothrix/Ilydrilus	*	*	Bi
Tardigrada		*	–	M
Oribatei		*	–	M
Cladocera	*Alona affinis* (Leydig)	*	–	D
	Alona costata Sars	*	–	D
	Alona sp.	*	–	D
	Chydorus sphaericus (Müller)	*	–	D

Table 2

ADDITIONAL SPECIES RECORDED IN THE PROFUNDAL FAUNAS OF LOCH NESS (≥200m) AND LOCH MORAR (≥300m) DURING 1991-93

Group	Species or Genus	Loch Ness	Loch Morar	Ident. By
	Chydorus sp.	*	–	D
	Eurycercus lamellatus Müller	*	–	D
	Monospilus dispar Sars	*	*	D
	Acroperus harpae Baird	–	*	D
Ostracoda	*Candona candida*	–	*	G
	Cryptocandona reducta	–	*	G
	Cypria ophthalmica	–	*	G
Harpacticoida	*Paracamptus schmeili* (Mraz)	*	–	H
	Atheyella crasse (Sars)	*	*	H
	Bryocamptus minutus (Claus)	*	–	H
Cyclopoida	*Paracyclops fimbriatus* (Fisch.)	*	–	Bo
Plecoptera	*Isoperla grammatica* (Poda)	–	*	Br
	Chloroperla torrentium (Pict.)	–	*	Br
Diptera	*Ablabesmyia* cf. *longistyla*	*	–	L
	Arctopelopia spp.	–	*	L
	Paramerina cf. *cingulata*	*	–	L
	Procladius (Holotanypus) sp.	*	–	L
	Macropelopia nebulosa (Meig.)	*	–	L
	Phaenopsectra flavipes (Meig.)	*	–	L
	Phaenopsectra not *flavipes*	*	–	L

Key: * recorded – not recorded

Bi - G. Bird
Bo - G.A. Boxshall
Br - S. Brooks
D - C. Duigan
G - H.I. Griffiths
H - R. Hamond
L - M. Learner
M - D.S. Martin
P - R.M. Pontin
S - F. Schiemer

Harpacticoid Copepoda

The same four species of harpacticoid copepods have been found by Holopainen and Paasivirta (1977) in the deep oligotrophic Lake Paajarvi, along with profundal nematode and chironomid species associations. In the Finnish Lake Paijanne, Sarkka (1992) found that *Attheyella crassa* showed a marked preference for the well-oxygenated end of this oligotrophic lake, which is undergoing eutrophication at the other end.

Cyclopoid Copepoda

Paracyclops fimbriatus, which is a crustacean preferring larger water bodies (Fryer, 1985), occurred in both Loch Ness and Loch Morar, and has been recorded by Dussart (1967) in Lake Geneva and by Sarkka (1992) in Lake Paijanne, where the profundal cyclopoids are species of *Diacyclops.* Another species commonly recorded in the profundal literature is *Megacyclops viridis,* which was often taken in the scoop samples and is a large enough animal to be a significant predator.

Conclusion

Without further study, it is difficult to determine whether the profundal benthos of these two deep Scottish lochs is a random collection of species populations accumulated over time, or a structured assemblage of interacting species populations of all trophic levels inhabiting the deep, cold, fine-structured and well-oxygenated loch sediments (Giller, 1984). The profundal benthos is surprisingly species diverse, and may well represent a saturated equilibrium community (that is, with filled ecological niches), as defined by Giller (1984). The age of the lochs, their environmental stability, their well-oxygenated conditions, and the not too low levels of organic food available in the sediments, all support this possibility.

Further biological studies on both the macrobenthos and meiobenthos should concentrate on quantifying both the vertical distributions and any differences between the North and South Basins in Loch Ness. In order to understand the role of the deep benthos on the loch ecosystem, there is also a need for life-cycle studies of the dominant species, by seasonal sampling and experimental rearing, and, later, unravelling the biotic interactions between species.

Acknowledgements

The Loch Ness and Morar Project would like to record its deep gratitude to the undernoted experts who gladly undertook the identification of specimens sent to them, without which Table 1 and Table 2 would not exist, or who contributed valuable assistance in other ways:

Dr. P.C. Barnard (Natural History Museum), Dr. J.A. Bass (Institute of Freshwater Ecology, I.T.E. Monks Wood), Dr. G. Bird (National Rivers Authority, Yorkshire Region), Dr. G.A. Boxshall (Natural History Museum), Dr. S. Brooks (Natural History Museum), Dr. P.C. Cranston (Natural History Museum, and C.S.I.R.O., Canberra, Australia), Dr. C. Duigan (Countryside Commission for Wales), Dr. J.P. Ellis (Natural History Museum), Dr. G. Fryer (Freshwater Biological Association), Mr. D.P. Gallagher (University of Dublin), Mr. R.B. Greer (Department of Agriculture and Fisheries for Scotland), Mr. H.I. Griffiths (University of Leeds), Mr. J.D. Hamilton (University of Paisley), Dr. R. Hamond, Dr. P.A. Henderson (Marine Biology Unit, Fawley), Dr. M.P. Kerney (Natural History Museum), Dr. M. Ladle (Institute of Freshwater Ecology, Wareham), Dr. M. Learner (University of Wales), Professor H. Löffler (University of Vienna), Mr. D.S. Martin (Loch Ness and Morar Project), Dr. P. Mordan (Natural History Museum), Dr. L.C.V. Pinder (Institute of Freshwater Ecology, I.T.E. Monks Wood), Dr. R.M. Pontin (Royal Holloway University of London), Professor F. Schiemer (University of Vienna), Dr. R.W. Sims (Natural History Museum), Dr. I. Strachan (Scottish Natural Heritage), Mr. A.C. Wheeler (Natural History Museum), and Dr. J.F. Wright (Institute of Freshwater Ecology, Wareham).

The Project also gratefully acknowledges help from Mr. John Minshull at Loch Ness, and the early enthusiastic contributions by Mr. Richard Grinvalds to the Loch Morar species list.

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Received June 1993

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THE SPATIAL DISTRIBUTION OF BENTHIC OSTRACODS IN THE PROFUNDAL ZONE OF LOCH NESS

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Introduction

In the early years of this century the late Sir John Murray commenced pioneer investigations into many aspects of Loch Ness (Murray, 1904 and 1908; Murray and Pullar, 1910), and some seventy-five years later this was followed by the extended survey carried out by Dr. Peter Maitland and his colleagues (Maitland, 1981), but much of the most recent work, particularly in the study of the benthic fauna, has not yet been published.

A preliminary analysis by Shine and Martin (1988) indicated that ostracod Crustacea ('seed shrimps') appeared to be an important component of the zoobenthos, numerically comprising almost 60% of the invertebrates in the deepest parts of the loch. Subsequently, both quantitative and qualitative studies of the ostracod fauna of Loch Ness were undertaken (Griffiths, Martin, Shine and Evans, 1993), and since then, additional data on the ostracods of the loch have become available, as well as a small dataset based on samples taken from the profundal benthos of Loch Morar. This current paper uses all these data to further investigate the patterns of distribution and community structure in benthic lacustrine ostracods.

Methods

Ostracods were collected both qualitatively, by dredging, and quantitatively, with a 15 x 15 cm Ekman grab, and a custom-built 10.3 cm diameter gravity corer. Ostracods were extracted by passing sediment samples through a bank of sieves down to 125 μm , and then by individually hand-picking specimens from sediment residues under a low-power dissecting microscope. Ostracods were killed in 30% ethanol, fixed in 70% ethanol, and identified using Henderson (1990), and Meisch

(1985) for *Potamocypris* sp. Taxonomic nomenclature follows Griffiths and Evans (1993).

Quantitative samples were used to assess ostracod densities in different areas of the loch. Qualitative data allow investigation of the proportional composition of the ostracod community, both as a whole (Figure 1), and in Urquhart Bay in the North Basin (Figure 2). On two occasions it was possible to extrude cores in such a way as to allow examination of the depth distributions of ostracods within sediments (Figure 3). Differences in ostracod densities in various parts of the loch were examined by Student's t-test (Parker, 1979).

Both the samples from Loch Morar result from qualitative sampling, but are treated in the same way as those from Loch Ness. Ostracod diversity from these samples was assessed by Brillouin's Index (HB) (see Magurran, 1988), allowing comparison with diversity values obtained from Loch Ness (Griffiths *et al.*, 1993).

Results

LOCH NESS

During the course of these studies, only the undernoted seven ostracod species were recovered from Loch Ness:

Candona angulata G.W. Müller, 1990

Candona candida (O.F. Müller, 1776)

Cryptocandona reducta (Alm, 1914)

Cypria ophthalmica (Jurine, 1820)

Cyclocypris ovum (Jurine, 1820)

Potamocypris smaragdina (Vavra, 1891)

Psychrodromus robertsoni (Brady and Norman, 1889)

In addition, *Candona neglecta* Sars, 1887 was reported from the loch in samples taken during the early 1980s, but has not been identified since. Of these taxa, specimens of the lotic water species *P. robertsoni* have only been recovered from the guts of Three-spined Sticklebacks *Gasterosteus aculeatus*, and are thought to have been ingested in one of the many streams which feed into the loch. The benthopelagic species *Cypria ophthalmica* is the commonest ostracod in Loch

Ness, making up over 61% of the entire fauna recovered. In contrast, *P. smaragdina* and *C. ovum* have only been encountered as one and two specimens, respectively.

The overall density of benthic ostracods in Loch Ness was reported as 262 ± 340 individuals/m^2 by Griffiths *et al.* (1993), who noted a clumped distribution within the ostracod taxocene as a whole. It has now been possible to examine densities in three areas within the loch: the South Basin, the North Basin, and Urquhart Bay.

The highest ostracod density yet identified is that of the South Basin (mean = 1,835 ostracods/m^2; extrapolated range between 0 and 7,284 individuals/m^2). The overall mean density in the North Basin is 125 ostracods/m^2 (extrapolated range between 0 and 657 individuals/m^2), but rather lower densities occur in Urquhart Bay (mean = 88 ostracods/m^2; extrapolated range between 0 and 205 individuals/m^2). Density comparisons within the North Basin are not statistically significant ($P > 0.05$), whereas a significant difference exists between the densities observed in the North and South Basins ($t = 2.76$, $P < 0.05$). Ostracod distributions are clumped in all these sub-divisions of the loch.

The two vertically sub-divided cores provide comparatively little information on depth distributions. The first 6.0 cm were examined of a core taken from 215 m in the North Basin (Figure 3a). Here *C. ophthalmica* occurred throughout the sediments, presumably burrowing deeply to feed. *Candona angulata* occurred to a depth of 5.0 cm, but *C. reducta* (which belongs to an infaunal genus) was only represented by a single individual. In the first 2.0 cm of the core taken from 150 m in the South Basin (Figure 3b), ostracods were present at higher densities. Only *C. ophthalmica* and *C. angulata* were present, the former in comparatively high numbers in the top 1.0 cm layer. The depth to which ostracods actually penetrate Loch Ness benthic sediments is currently unknown, although it is surprising to find the benthopelagic form *C. ophthalmica* at these depths in the sediments.

LOCH MORAR

The Loch Morar samples were both taken from a depth of 300 m on 8th June 1992, and the fauna identified in the two samples are listed below:

The fauna of the two Loch Morar samples are fairly similar to the samples from Loch Ness, except that one benthic species (*C. angulata*) is absent, although the free-swimming form *C. ovum* is present in relatively high numbers. Species richness (four taxa) is similar to that found in much of Loch Ness, and in other

Figure 1

Proportional Composition of the Benthic Ostracod Fauna of Loch Ness

The area below the 200 m isobath is shown

Numbers represent sample sizes

U = Urquhart Bay.

N

U

292

91

41

24

213

58

37

14

119

49

37

70

25

25

Cypria
ophthalmica

Candona
angulata

Cryptocandona
reducta

Candona
candida

Other taxa

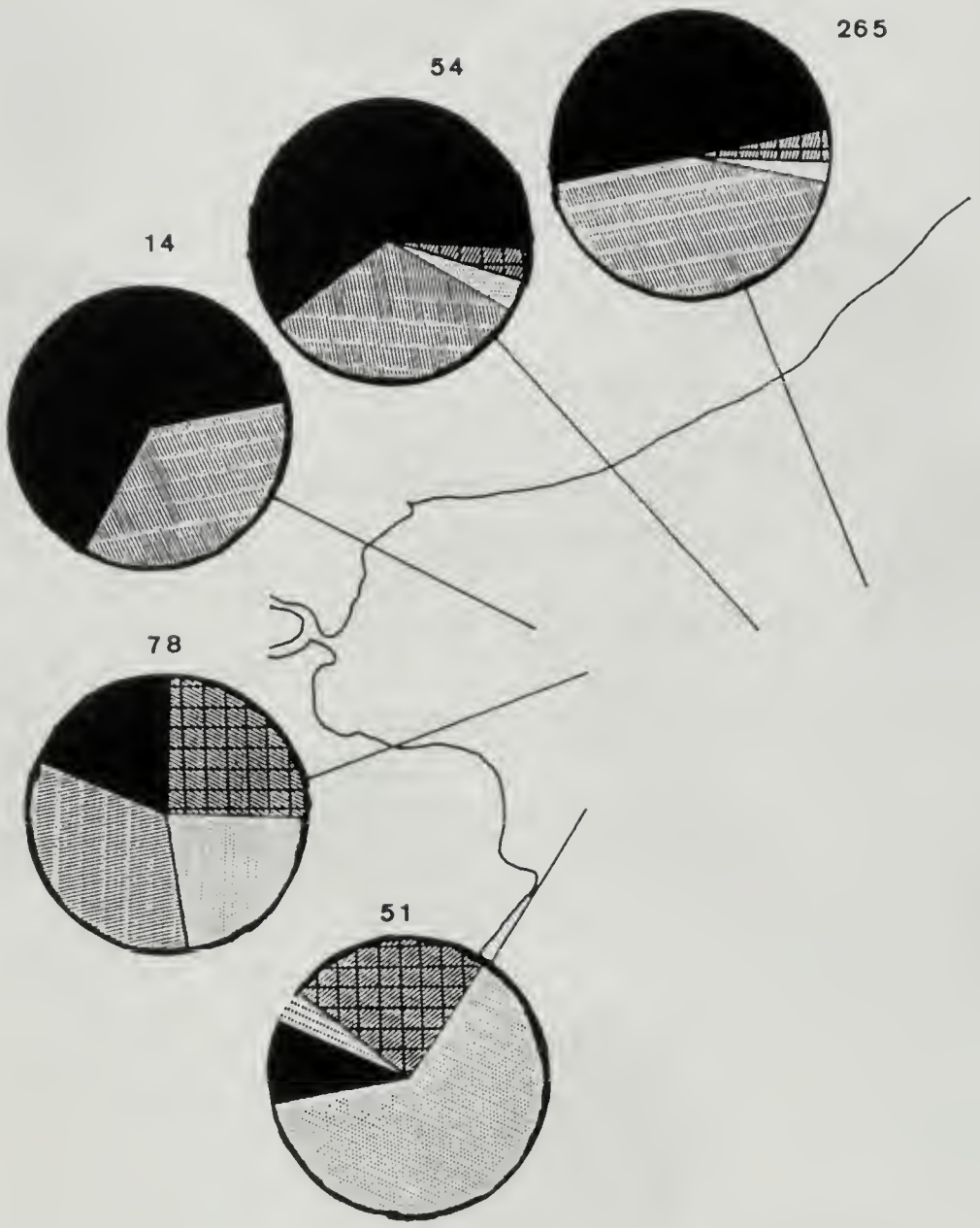

Figure 2

Proportional Composition of the Benthic Ostracod Fauna of Urquhart Bay

Numbers represent sample sizes

Species Key as in Figure 1.

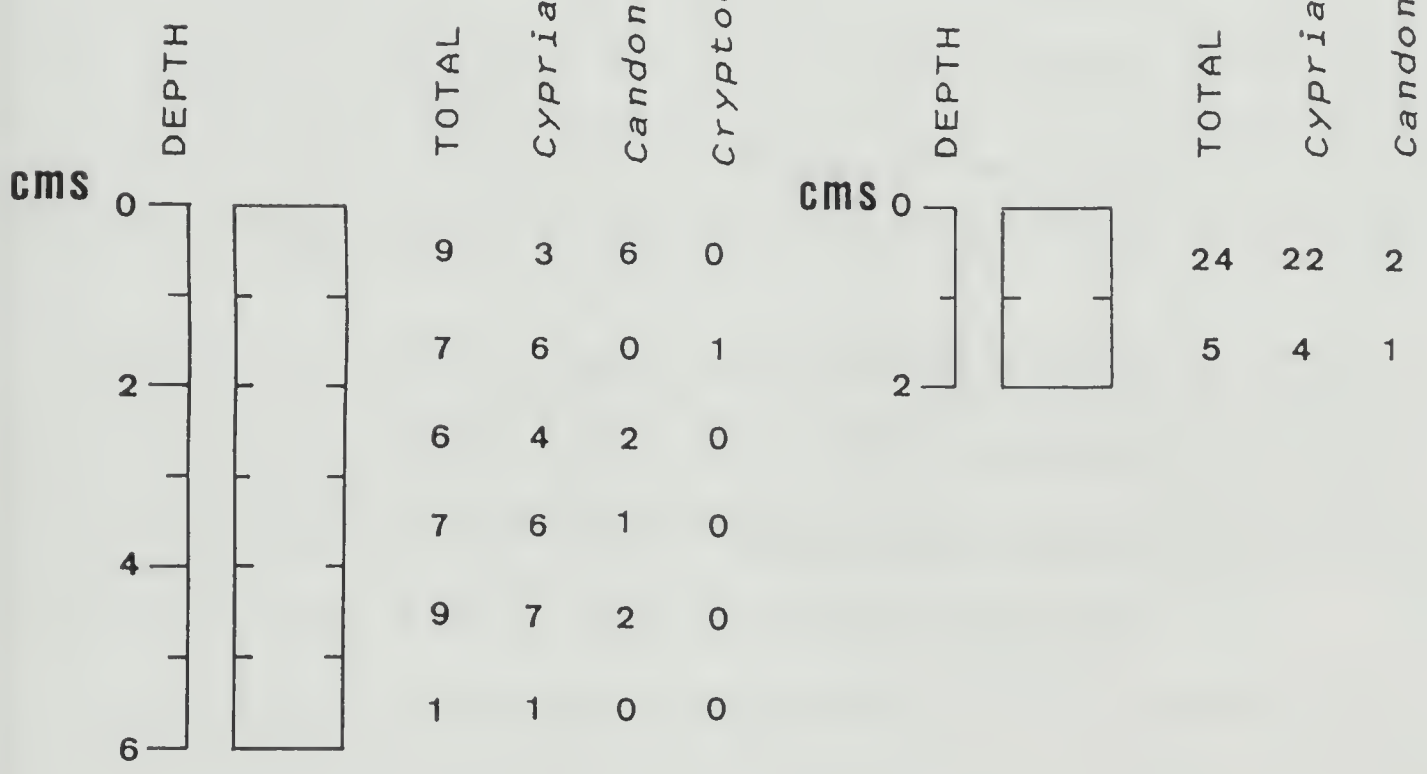

Figure 3

Depth Distribution of Ostracods within Sediment Cores

(a) 6.0 cm core from 215 m, mid-loch in North Basin.

(b) 2.0 cm core from 150 m, mid-loch in South Basin.

oligotrophic temperate lakes, but HB values are within the upper range of the values reported from Loch Ness (Griffiths *et al.*, 1993). As far as we are aware, these samples (from 300 m) represent the deepest records yet known for *C. ovum.*

Sample No.	Species	Adults	Juvs.	HB
1	*Cypria ophthalmica*	39	0	
	Candona candida	22	7	
	Cryptocandona reducta	1	2	
	Cyclocypris ovum	14	2	1.08
2	*Cypria ophthalmica*	39	5	
	Candona candida	1	4	
	Cryptocandona reducta	2	0	
	Cyclocypris ovum	17	2	0.86

Discussion

Griffiths *et al.* (1993) have shown that no correlations exist between depth and either ostracod diversity or the abundance of individual species within the loch. Comparison of the ostracod communities in the North and South Basins (Figure 1) shows that species-richness is lowest at the southern end of the South Basin, where the influence of the River Oich is greatest (Bennett, 1993). Species-richness remains at either 3.0 or 4.0 throughout much of the loch's length, only reaching 5.0 in the upper, shallower reaches of the North Basin. Within Urquhart Bay (Figure 2), which comes under the influence of the Rivers Enrick and Coiltie, the community appears to be a little more uniform in composition, although ostracod distributions are still clumped (see Elliott, 1977).

It is clear that ostracod densities are considerably higher in the South Basin than in the North, and this is believed to reflect the higher sedimentation rate of the South Basin, coupled with quantitative increases in the levels of organic inputs.

However, this increase is not accompanied by increases in either diversity or species-richness. The latter never rises above 4.0 in the South Basin, and several samples consisted only of *C. ophthalmica* and *C. angulata*, both of which are eurytopic, hardy species. *Candona candida* was largely absent from the South Basin, except in deep-water samples, possibly suggesting that *C. candida* is sensitive to some aspect of the conditions associated with higher levels of sediment deposition.

The sediments of the deeper parts of the loch are primarily of laminated muds, with areas of sand or organic-rich sands in the vicinities of river mouths (Bennett, 1993). However, there appears to be little linkage of fauna and sediment type, even when the sandy, organic substrata of Urquhart Bay are compared with the remainder of the loch. This provides further evidence that the restricted ostracod fauna of Loch Ness is (to some degree at least) a product of the homogeneity of the benthic sediments (Griffiths *et al.*, 1993).

The use of ostracods in palaeolimnological analysis at Loch Ness has so far proved impossible. The sediments are predominantly acidic, which causes rapid *post-mortem* degradation of ostracod valves. Despite this, it is believed that the loch has represented a comparatively stable environment, at least since 1868, when a catastrophic flooding event (Anon., 1868; Barron, 1985) resulted in the deposition of a layer of clay throughout the benthos (Bennett, 1993).

The benthic fauna of a given water-body must largely be determined by site-based variables (abiotic interactions), the influence of biotic constraints becoming more apparent over time (Forester, 1991). Griffiths and Evans (1992) have argued that the co-occurrence of several related ostracod species (e.g. congeners) reflects niche-packing, since species which are essentially similar in their modes of life partition the resources available.

At Loch Ness, many of the benthic samples contain three closely-related species: *C. angulata, C. candida* and *C. reducta*, plus *C. ophthalmica*. Of these, the first two are semi-infaunal, and *C. reducta* is markedly so. *Cypria ophthalmica,* however, is free-swimming and hardy. Combinations of these species (or a variant composed of *C. neglecta* rather than *C. angulata*) are also present in Loch Morar, at Cosemeston Lakes in South Wales (Griffiths and Evans, 1991) and elsewhere (e.g. Löffler, 1975; Jónasson, 1978; Danielopol *et al.*, 1985). This may suggest some sort of 'stable' ecological unit, pre-adapted to partitioning simple benthic habitats. Since this faunal unit is so widespread, it also suggests the question, - to what extent are benthic niches pre-empted? - (see Krebs, 1985). The presence of this fauna may simply reflect the inability of other groups to survive in

these environments, but its recurrence perhaps does suggest a colonising fauna which, once established, is difficult to displace. The presence of such a faunal element, exhibiting a high degree of niche pre-emption, would also act to limit benthic colonisation, and restrict incoming colonists to littoral habitats, or to other, possibly less favoured, niches.

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Received May 1993

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THE FOOD AND FEEDING RELATIONSHIPS OF PELAGIC FISH IN LOCH NESS

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Introduction

This paper is concerned with the food and feeding relationships of the pelagic Charr *Salvelinus alpinus* and Brown Trout *Salmo trutta* of Loch Ness, with some observations on the Three-spined Stickleback *Gasterosteus aculeatus* population also present in the loch.

The glaciated, tectonic fault origins of Loch Ness have created a remarkably regular basin, i.e. steep sides sloping to a flat bed, with a maximum depth of 230 m and the greatest mean depth (132 m) of any British lake.

Just over half (50.9%) of the loch's surface covers a water depth greater than 150 m, and 27.2% of the surface covers over 200 m depths. Such a distinct pelagic zone is easily defined in relation to the other two zones, the narrow littoral/sublittoral and the deep profundal.

Yet despite the vast volume of this open water, in terms of fish population this zone has not previously been studied. Baker (1962) speculated that the fish consisted of a layer of Charr at about 30 m depth across the loch, with Brown Trout moving offshore near to the surface from the littoral zone, but this work was never supported by sampling. Maitland (1981) concentrated his fish survey on commercial species within the littoral.

Since the early 1980s, members of the Loch Ness and Morar Project, in collaboration with the Ness Fisheries Board, together with Dr. Annie Duncan and Mr. R.B. Greer, have conducted a pelagic zone programme, mainly from fixed stations positioned mid-loch in the deepest water. Echo-sounding shows fish throughout the water column but mainly in the top 40 m. Sampling has revealed that the offshore waters to 30 m depth are dominated by Charr, with Brown Trout extending over the surface (Shine and Martin, 1988), and with larger, piscivorous Ferox Trout within and beneath the Charr layer. Three-spined Sticklebacks are also significant residents in this zone, particularly in the South Basin, but Salmon

parr *Salmo salar* and Lamprey *Lampetra* sp., both rarely observed, are not thought to contribute significantly.

Materials

The material for this study is based on 108 Charr and 46 Brown Trout caught between 1982 and 1992, and derived from four sources. Firstly, the majority were caught in depth-marked gill nets, of various mesh size suspended from a fixed station, mostly from evening until the following mid-morning. The stations, mid-loch and at least 0.5 km from either shore, lay in water depths exceeding 190 m.

Secondly, in collaboration with the Department of Agriculture and Fisheries for Scotland's (D.A.F.S.) research vessels *Goldseeker* and *Calanus*, mid-water trawling has contributed a total of 154 fish, of which 50 are Sticklebacks and so not part of this study.

Thirdly, incidental pelagic fish have been captured on the descent phase of gill nets, which have to pass through the surface waters en route to the profundal zone.

Finally some Charr, extracted from the stomachs of pelagic caught Brown Trout, have themselves been analysed for their gut contents.

Offshore fish, i.e. not caught mid-loch, have not been considered in this study.

Methods

After weighing, measuring, and sex determination of each fish, the alimentary canal was dissected, and separated into three regions: the stomach, pyloric caecae, and intestine, which were analysed separately under a light microscope, or the contents preserved in 70% ethanol for later analysis.

The initial records exist in the form of percentage food item of the overall contents, for each of the three gut regions, but for the purposes of this study and to give a better general presentation, the figures have been converted to the following letters: D, i.e. Dominant prey item, 100% - 50% of total food contents; S, i.e. Significant prey item, 50% - 5.0% of total food contents; or O, i.e. <5.0% or only observed as an occasional food item.

Evaluation of the gut contents has been made by a Points System, derived from Swynnerton and Worthington (1940). Fullness of actual stomach has not been considered, however, since many fish regurgitate their stomach contents when

trapped in gill nets, and in any case the overall gut content of each fish is being considered. For this study, the D value was allocated 2.0 points, the S value 1.0 point and the O value 0.1 points. Such a system takes into account the contents of the complete fish from the three gut regions investigated separately.

The otoliths were removed for ageing by Mr. R.B. Greer.

As far as possible, fish were collected throughout the year, but winter pelagic fish were difficult to sample, since many disperse inshore to the side walls of the loch, or exist in a state of lethargy and so do not get caught in gill nets. Those which were caught (February and March) had no gut contents for inclusion here.

Results

The results are summarised in Tables 1-7 and Graph 1.

Table 1 shows the breakdown of the food components for each of the three regions of the gut to emphasise the dominance (D), significance (S), or mere presence or otherwise (O) of any prey item. This is then collectively summarised on the Points System in the final column.

The fish were numbered by the month caught, regardless of year, and in ascending weight per month. The relationship between Length and Age is presented in Graph 1.

It is significant that the composition of food was often different within the separate gut regions of an individual fish; e.g. Charr #72 had a 9.1 ratio of *Daphnia: Bythotrephes* in the stomach, but the reverse of this in the intestine.

Similarly, a prey item absent in the stomach could be dominant in the intestine; e..g. Brown Trout #9 with *Daphnia* and *Bythotrephes.* Even equal-sized fish caught in the same gill-netting operation could have distinctly differing compositions of food within the gut; e.g. Charr #40 dominated by Chironomid larvae, and Charr #43 dominated by *Bythotrephes.*

The Points System column reduces this complexity to allow patterns to emerge, as seen in Tables 2 and 3.

In terms of the most frequently selected prey item, the Charr diet is dominated by the larger Cladocera, *Bythotrephes longimanus, Daphnia hyalina* and *Leptodora kindti*, in that order, with Chironomid larvae an important component.

Table 1

Food of Pelagic Fish in the Three Regions of the Gut
(Collectively summarised as a Points System)

Key to species headings in gut:

Daphnia
Bythotrephes
Leptodora
Bosmina
Fish (R = remains)
Chironomids
Aerial Insects
Other

Key to 'Other' column in gut:

Aq - Aquatic Insects
Ben - Benthos
Bo - *Bosmina*
Cla - Cladocera
Cop - Copepods
Cyc - *Cyclops*
Dia - *Diaptomus*
Pim - *Pisidium*
Pol - *Polyphemus*

Symbols:

D : Dominant; prey item 100% → 50% of total food content per gut region.

S : Significant; prey item 50% → 5% of total food content per gut region.

O : Occasional; prey item 5% or less of total food content per gut region.

Points System:

D - 2.0 points; S - 1.0 point; O - 0.1 points.

							STOMACH							PYLORIC CAECAE							INTESTINE							TOTAL GUT (POINTS SYSTEM)						
MONTH	NO.	L. cm.	WT. g.	SEX	AGE		DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	AERIAL INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	AERIAL INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	AERIAL INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	AERIAL INSECTS	OTHER
MAY	1	15·9	39·1	F			D	O																				2	·1					
JLY	2	16·2	46	F			D	O						D							D							6	·1					
	3	16·6	48·2	F			S	S				O																1	1				·1	
	4	16·9	55·9	F			D	O																				2	·1					
	5	17·6	74	M	4+		S	D	O	O		O									S	D				O		2	4	·1	·1		·2	
	6	25·0	149	F	6+		S	D				O	1 Cyc								S	S		O				2	3		·1		·1	1 Cyc
	7	24·7	164·6	M			S	S																				1	1					
	8	27·3	203	F			S	D				O	1 Cyc								O	D						1·1	4				·1	1 Cyc
AUG	9	5·5	1·8	F	1+		S	D													S	D		S				2	4		1			
	10	5·7	1·9		1+						S	S	D Ben					S		D Ben					S	S	D Ben					3	2	6 Ben
	11	5·9	2·1		1+		S	S																				1	1					
	12	6·0	2·2		0+						S	S													S	S	S 1 Pim					2	2	1 1 Pim
	13	6·1	2·3		1+				O		S	S	D Ben					S		D Ben					S	S	D Ben			·1		3	2	6 Ben
	14	6·0	2·6		1+			S			D				S	S						D	S						4	2		2		
	15	7·1	3·8		1+		O	D		O					D													·1	4		·1			
	16	7·2	3·8		1+		D	S	S	O				S	S	S					S	S	S						4	3	3	·1			
	17	7·4	4·1		1+		S	D	S					S	D	S						D	S		S		S Pim 1		2	6	3		1		1 Pim 1
	18	7·4	4·1				S	S	S					S	S	D						D	S						2	4	4				
	19	7·0	4·2				D		S		S			S	S	S	S	S			S	D	S		S				4	3	3	1	3		
	20	7·2	4·8				D	S	S	O											S	S	D	S					3	2	3	1·1			
	21	8·6	6·4				O	S	D	O				S	S	S	S	S			O	S	S		S				1·2	3	4	1·1	2		
	22	8·8	7·1				S	D	O					S	D			S			O	D	O		S				2·1	6	·2	2			
	23	9·3	8·2						D							D	S	S	S		O	S	D	O	S				·1	1	6	1·1	2	1	

② CHARR

MONTH	No.	L. cm.	WT. g.	SEX	AGE	STOMACH DAPH.	STOMACH BYTHO.	STOMACH LEPTO.	STOMACH BOSMINA	STOMACH CHIRDS	STOMACH NEARL INSECTS	STOMACH OTHER	PYLORIC CAECAE DAPH.	PYLORIC CAECAE BYTHO.	PYLORIC CAECAE LEPTO.	PYLORIC CAECAE BOSMINA	PYLORIC CAECAE CHIRDS	PYLORIC CAECAE NEARL INSECTS	PYLORIC CAECAE OTHER	INTESTINE DAPH.	INTESTINE BYTHO.	INTESTINE LEPTO.	INTESTINE BOSMINA	INTESTINE CHIRDS	INTESTINE NEARL INSECTS	INTESTINE OTHER	TOTAL GUT (POINTS SYSTEM) DAPH.	TOTAL GUT BYTHO.	TOTAL GUT LEPTO.	TOTAL GUT BOSMINA	TOTAL GUT CHIRDS	TOTAL GUT NEARL INSECTS	TOTAL GUT OTHER
	24	10·1	10·6		2+	S	D	S	S	S					D						S	D					1	3	5	1	1		
	25	10·4	11·6		2+	S	D	S		S											D			S			1	4	1		2		
	26	10·5	11·8			S	S	S	o	S			S		D			o		S	D	S	o	S			3	3	4	·2	2	·1	
	27	10·7	11·9		2+	S	S	S	S	S				D	S					o	S	S	S				1·1	4	3	2	1		
	28	10·6	12·4	F	2+									S			D				S			D				2			4		
	29	10·6	12·5	F	2+			o		D		S Pim					D				S	S		D				1·	1·1		6		1 S Pim
	30	10·7	13·5			S	D							S					D Pim		S	S		S		S Ben	1	4	1		1		3 Pim³ Ben³
	31					o	D		o	o										o	D						·2	4		·1	·1		
	32	15·5				D	S													D	S						4	2					
	33	14·5				D	S				o																2	1				·1	
	34	12·4	18·8		3+	S	S	S	o	S										o	S	S					1·1	2	2	·1	1		
	35	12·6	19·1				S	S			S			S	S			S			D	S		S	S			4	3		1	3		
	36	12·9	19·6	F		S	D		o				S	D							D			o	o	P Pim	2	6		·1	·1	·1	P Pim
	37	12·6	20·2		2+		D														D	S		S				4	1		1			
	38	12·9	20·9	F	2+	S	S	S		S				D	S						D	S		S			1	5	3		2		
	39	13·9	25·8		3+	o	S	S		S				S	S		D			o	S	S		S			·2	3	3		4		
	40	15·1	31·4		4+		S	S		D							D				o	o		D	o			1·1	1·1		6	·1		
	41	14·8	35·0				D			o										o	D	o					·1	4	·1		·1		
	42	13·9	35·4	F		D	o																				2	·1					
	43	15·9	40·0	F	3+	S	D		o	o				D						S	D		S				2	6		1·1	·1		
	44	16·3	48·5			S	D																				1	2					
	45	16·7	50·0																	S	S						1	1					
	46	17·4	51·5	F	4+		D	S		S				S	S		o				D	S		S				S	3		2·1			
	47	17·9	52·8	F			S	S		D				S	S		o							D				2	2		4·1			
	48	17·8	55·9	F			S	o		D	o			S			D							D				2	·2		6			

							STOMACH							PYLORIC CAECAE						INTESTINE							TOTAL GUT (POINTS SYSTEM)						
MONTH	No.	L. cm	WT. g.	SEX	AGE		DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	ACARAL INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	ACARAL INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	ACARAL INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	THORAL INSECTS	OTHER
	49	19.5	78	F	4+		S	D					1 Pol		D						0	S			0			1.1	5			.1		1 Pol
	50	21.0	107	F	5+			D			0				D						0	D		0				.1	6		.1	.1		
	51	21.8	118	F	6+		0	D		0					D						0	D		0	0			.2	6		.2	.1		
	52	21.0	127	M	3+		D	S													D	S						4	2					
	53	23.1	130	M	5+		0	D		S	0				D						0	D		0		0		.2	6		1.1	.1	.1	
	54	23.3	145	F	6+		0	D					1 Pol		D							D		0				.1	6		.1			1 Pol
	55	23.0	146	M	4+		S	S													S	S						2	2					
	56	22.6	147.6	F			D	0																				2	.1					
	57		156.6	F	6+			S	S		D							D			0	S	S		0	0			.1	2	2		4.1	.1	
	58	24.1	157.1	F			S	D																				1	2					
	59	25.9	197	F	6+																													
	60	27.7	201	M	7+		S	D	S			S			D				0		S	D			0			2	6	1		.2	1		
	61	28.1	207	F	7+		0	D			0			D	S	S					0	D			0	0		2.2	5	1		.2	.1		
	62	24.8	212	M	4+		D	S						D							S	S						5	2					
	63	27.5	212	F	6+		0	D		0	0		1 Cyc		D				0		0	D			S	0		.2	6		.1	1.2	.1	1 Cyc	
	64	27.0	226	F	6+																													
	65	26.5	231	F			D	S						D	0						D							6	1.1					
	66	28.3	244	M			D	S													D	S						4	2					
	67	27.7	249	M			S	D																				1	2					
	68	27.7	261	F	4+		S	D													S	S						2	3					
	69	27.6	268.5				S	D																				1	2					
	70	28.0	285	F			0	D			0										0	D						.2	4			.1		

④ CHARR

							STOMACH							PYLORIC CAECAE						INTESTINE							TOTAL GUT (POINTS SYSTEM)						
MONTH	No.	L. cm	WT. g.	SEX	AGE		DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	AERIAL INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	AERIAL INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	AERIAL INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	BOSMINA	CHIROS.	AERIAL INSECTS	OTHER
SEPT	71	7·3	4·0				S	D	S																			1	2	1				
	72	20·7	98	F	3+		D	S						D	S						S	D							5	4					
	73	20·5	110	M	4+		D	S						D	S	o					S	S			o				5	3	·1		·1		
	74	20·6	113	M	5+		S	D						D	S						S	S							4	4					
	75	25·0	197	M			D	o						D	o	o					D								6	·2					
	76	25·8	268	F			D	o													D	o							4	·2					
	77	27·0	236·5	M			D														D	o							4	·1					
	78	28·1	250·3	M			D		o												D	o	o						4	·1	·2				
	79	27·5	261·8				D	S													D	o							4	1·1					
	80	28·1	264	M	4+																														
	81	28·2	266				D	o													D	o							4	·2					
	82	27·8	271	F	6+										D			S				S			D					3			3			
	83	29·8	275	F	5+		S	S				o									S	D							2	3				·1		
	84	29·7	297	F	5+		o	D			o				D			o	o		o	D							·2	6			·2	·1		
OCT	85	4·0					D	o																					2	·1					
	86	7·2					D	S																					2	1					
	87	9·0					D						o Pim 3														D Pim 2		2					2·1 Pim 5	
	88	10·8					D	o			o																		2	·1			·1		
	89	11·3					S	D																					1	2					
	90	27·8	285				S	S			o	o		D	S			o	o		S	S			o	o			4	3			·2	·2		
NOV	91	3·0	0·25		O+			S	S														S				D 3 Cyc			1	2			2 Cyc 3	
	92	3·2	0·3		O+				S				D Ben						D Ben												1			4 Ben	
	93	3·3	0·3		O+		S				S		D Cyc 8														D 1 Cyc		1				1		4 Cyc 9	

(5) CHAKR

MONTH	No.	L. cm	WT. g.	SEX	AGE	STOMACH DAPH.	STOMACH BYTHO.	STOMACH LEPTO.	STOMACH BOSMINA	STOMACH CHIROS.	STOMACH NEURAL INSECTS	STOMACH OTHER	PYLORIC CAECAE DAPH.	PYLORIC CAECAE BYTHO.	PYLORIC CAECAE LEPTO.	PYLORIC CAECAE BOSMINA	PYLORIC CAECAE CHIROS.	PYLORIC CAECAE NEURAL INSECTS	PYLORIC CAECAE OTHER	INTESTINE DAPH.	INTESTINE BYTHO.	INTESTINE LEPTO.	INTESTINE BOSMINA	INTESTINE CHIROS.	INTESTINE NEURAL INSECTS	INTESTINE OTHER	TOTAL GUT (POINTS SYSTEM) DAPH.	TOTAL GUT BYTHO.	TOTAL GUT LEPTO.	TOTAL GUT BOSMINA	TOTAL GUT CHIROS.	TOTAL GUT NEURAL INSECTS	TOTAL GUT OTHER
	94	3.6	0.35		0+					S		D Ben																			1		2 Ben
	95	3.6	0.4		0+		S			S	S	D Cop												S	S	D Ben		1			2	2	4 Cop
	96	4.0	0.45		0+			S				D Ben										S				D Ben			2				4 Ben
	97	5.4	0.9		0+	D																					2						
	98	4.9	1.15		0+					S	S	D Ben										S			S	D Ben			1		1	2	4 Ben
	99	5.5	1.35		0+			S				S 2 Cyc																	1				1 2 Cyc
	100	5.3	1.4		0+							D 1 Cyc														D Ben							4 Ben Cyc 1
	101	5.6	1.45		0+	D							D														4						
	102	5.3	1.5		0+	D	S		0											D			0				4	1		.2			
	103	5.5	1.55		0+						S	D 2 Pim										S				D Ben				1		1	4 Pim 2 Ben
	104	5.5	1.7		0+																												
	105	5.9	1.8			D		0		0		S 3 Cyc / S 1 Cop								D							4		.1		.1		1 3 Cyc / 1 Cop
	106	6.1	2.25			S																					1						
	107	11.1	14.3			D		0																			2		.1				
	108	11.8	18.3			D																					2						

① BROWN TROUT

							STOMACH							PYLORIC CAECAE							INTESTINE							TOTAL GUT (POINTS SYSTEM)						
MONTH	No.	L. cm	Wt. g.	SEX	AGE		DAPH.	BYTHO.	LEPTO.	FISH	CHIROS.	ACARI, INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	FISH	CHIROS.	ACARI, INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	FISH	CHIROS.	ACARI, INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	FISH	CHIROS.	ACARI, INSECTS	OTHER
MAY	1	20·4	82	F								D														D							4	
JULY	2	4·8	<2		0+																													
	3	21·2	113·9									D														D							4	
	4	32·3	402	M							S	S											D	S R						2	1	1	1	
	5	47·4	1016·6	F						D		S												D							4		1	
AUG	6	20·3	80				S	S				D																1	1				2	
	7	21·5	119	M			S	S				0									S	S			0	D		2	2			·1	2·1	
	8	22·7	147	M				S			0	S										D				0			3			·1	1·1	
	9	23·0	148	F								D									D	S			0	0		2	1			·1	2·1	
	10	23·5	149	F				0				D										D							2·1				2	
	11	24·0	180	F				S				D										D				S			3				3	
	12	24·2	236				0	D				S	1 Pol															·1	2				2	1 Pol
	13	32·7	357	F			0	S		D	0																	·1	1		2	·1		
	14	38·7	650	M						D														D R						2	4			
	15	46·0	1045							D½														D R						2	6			
SEPT	16	20·4	94				D	S						D	S	0					S	S				S		5	3	·1			1	
	17	30·0	312				D	S				S																2	1			1		
	18	35·2	426	F								D									D	S	0		0	S		2	1	·1		·1	3	
	19	38·3	630									D						S	D		S	S			0	S		1	1			1·1	5	

							STOMACH							PYLORIC				CAECAE		INTESTINE							TOTAL CUT (POINTS SYSTEM)						
MONTH	NO.	L. cm	WT. g.	SEX	AGE		DASH.	BYTHO.	LEPTO.	FISH	CHIROS.	NEMAT. INSECTS	OTHER	DASH.	BYTHO.	LEPTO.	FISH	CHIROS	NEMAT. INSECTS	OTHER	DASH.	BYTHO.	LEPTO.	FISH	CHIROS	NEMAT. INSECTS	OTHER	DASH.	BYTHO.	LEPTO.	FISH	CHIROS	NEMAT. INSECTS	OTHER
OCT	20	26·0	190	F								D							D			0	0			D			·1	·1			6	
	21	26·7	194·5	F						D							D							D R							6			
	22	27·3	206·3				S	S				S									S	S				S		2	2				2	
	23	26·9	218·4									D							D		S	S				S		1	1				5	
	24	27·9	224·8					S				S							D							D.			1				5	
	25	27·5	234·3				S	S				0	Cyc¹	S	S						S	S						3	3				·1	Cyc¹	
	26	29·2	267·2																		D	S						2	1					
	27	29·4	290									D														D							4	
	28	32·0	297·6																															
	29	30·4	301·4				D	S				0		D	S				0	Bo¹	S	S						5	3				·2	Bo¹	
	30	29·5	308·4							D														D R							4			
	31	32·9	358·2				S	D													S	S				S		2	3				1		
	32	35·9	449·8																					D R							2				
	33	35·0	460·4				S	S			0			S	S														2	2			·1			
	34	35·2	471·9	F						D							D							D R							6				
	35	34·7	501·6	F						D							D							D R							6				
	36	35·5	507·8	F						D_3							D							D R			Pim¹				10			Pim¹	
	37	38·2	530·8																					D R							2				
	38	40·6	715·1							D							D							D R							6				
	39	45·5	936·5							D_2							D							D R							8				
	40	46·7	1020							D							D							D R							6				
	41	47·7	1027·9														D							D R							4				
	42	48·1	1144																																
	43	52·4	1674·5							D_2							D							D R							8				
	44	57·9	2033·5	F						D_2							D							D R							8				

③ BROWN TROUT

						STOMACH							PYLORIC CAECAE							INTESTINE							TOTAL GUT (POINTS SYSTEM)						
MONTH	NO.	L. cm.	WT. g.	SEX	AGE	DAPH.	BYTHO.	LEPTO.	FISH	CHIROS.	AQUAT. INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	FISH	CHIROS.	AQUAT. INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	FISH	CHIROS.	AQUAT. INSECTS	OTHER	DAPH.	BYTHO.	LEPTO.	FISH	CHIROS.	AQUAT. INSECTS	OTHER
NOV	45	5.1	1.2		0+							Aq^R D								S						S $Cl_2{}^R$	1						3 Aq Cl
	46	5.7	1.8		0+																											
	STICKLEBACK																															
AUG		4.3	0.8									D 1 Cyc																				2 1 Cyc
		4.5	1.2																													
NOV		5.0	1.0	F								Bo^1 Cyc^1								D						S Bo^3	2						1 Bo^4 Cyc^1
		4.9	1.25	F																												
		5.5	1.6	F		D						Bo^4 Cyc^2 Dia^1								D							4						Bo^4 Cyc^2 Dia^1

The presence of benthic fauna is also of interest. Unlike Charr, Brown Trout most frequently select fish, followed by aerial insects, with *Daphnia* and *Bythotrephes* the third and fourth most selected prey respectively. Brown Trout predate very few chironomids, and benthic fauna is noticeably absent.

Table 3 summarises the dominance of one prey item over all the others within the gut, i.e. where the points for a single prey item are greater than the sum of all the others. The inference is that, given a choice, the fish would prefer particular prey. Here the preferred items were *Daphnia* and *Bythotrephes* for the Charr, and quite clearly fish for the Brown Trout.

Table 4 presents the percentage of each fish species containing evidence of a prey item, regardless of the quantity of material eaten. Thus *Bythotrephes,* followed by *Daphnia*, were taken by over 75% of the Charr sampled, with chironomid larvae and *Leptodora* present in over 43% and 37% of these fish respectively. Nearly half the Brown Trout contained aerial insects to some degree, followed by *Bythotrephes,* fish and then *Daphnia* in nearly 37% of all the Trout analysed.

The diversity of prey items selected by the different salmonids is shown in Table 5. Charr, in general, forage on a greater number of prey taxa than do Brown Trout, i.e. they are able to exploit a wider food source.

It would appear that, in the months represented in this study, *Bythotrephes* is the most important cladoceran prey item in July and August, but is superseded by *Daphnia* in September, October and November. Chironomids and *Leptodora* were especially present in August. Table 6 supports Maitland's findings (1981) that the *Daphnia* population in Loch Ness peaks in October and that *Bythotrephes* peaks in July, although Walker, Greer and Gardner (1988) suggest there is little seasonal variation apparent in the proportions of organisms eaten by Charr in Loch Rannoch.

Discussion

The diet of the pelagic Charr in Loch Ness is dominated numerically by the larger Cladocera: *Bythotrephes longimanus, Daphnia hyalina* and *Leptodora kindti* in that order. A similar situation is true for pelagic Charr in Loch Rannoch (Walker *et. al.*, 1988), in Lake Windermere and other water bodies of the English Lake District (Frost, 1977), as well as in lakes elsewhere, including Austria (Steinböck, 1949), Norway (Dahl, 1920), and Sweden (Nilsson, 1955), although the proportion in the diet varies.

	CHARR		BROWN TROUT	
	TOTAL POINTS	%	TOTAL POINTS	%
DAPHNIA	172·9	26·55	36·0	15·46
BYTHOTREPHES	235·8	36·20	34·2	14·69
LEPTODORA	75·4	11·58	6·3	2·71
BOSMINA	14·1	2·16	—	—
COPEPODS	13·0	2·0	—	—
CHIRONOMIDS	77·4	11·88	3·7	1·59
FISH	—	—	93·0	39·95
PISIDIUM SP.	6·1	0·94	—	—
OTHER BENTHOS	37·0	5·68	—	—
AQUATIC INSECTS	—	—	3·0	1·30
AERIAL INSECTS	19·6	3·01	56·6	24·31
TOTAL	651·3	100·31	232·8	100·01

Table 2

Most Frequently Selected Prey Items
for Charr and Brown Trout

	CHARR		BROWN TROUT	
	TOTAL POINTS	% TOTAL FISH	TOTAL POINTS	% TOTAL FISH
DAPHNIA	28	25·93	3	6·52
BYTHOTREPHES	27	25·0	2	4·35
LEPTODORA	1	0·93	—	—
BOSMINA	—	—	—	—
COPEPODS	1	0·93	—	—
CHIRONOMIDS	5	4·63	—	—
FISH	—	—	19	41·30
PISIDIUM SP.	—	—	—	—
OTHER BENTHOS	6	5·56	—	—
AQUATIC INSECTS	—	—	1	2·17
AERIAL INSECTS	—	—	7	15·22

Table 3

Preferred Food Items:
Dominance of One Species of Prey over all the Others.

	CHARR		BROWN TROUT	
	Nos.	%	Nos.	%
DAPHNIA	82	75·92	17	36·96
BYTHOTREPHES	86	79·63	21	45·65
LEPTODORA	41	37·96	6	13·04
POLYPHEMUS	2	1·85	1	2·17
BOSMINA	23	21·30	1	2·17
COPEPODS	9	8·33	1	2·17
CHIRONOMIDS	47	43·52	9	19·57
FISH	—	—	18	39·13
PISIDIUM SP.	7	6·48	1	2·17
OTHER BENTHOS	9	8·33	—	—
AQUATIC INSECTS	—	—	3	6·52
AERIAL INSECTS	24	22·23	22	47·83

Table 4

Percentage of Fish containing Specific Food Items, regardless of quantity.

No. of PREY TAXA	CHARR		BROWN TROUT	
	No.	%	No	%
0	5	4·63	4	8·70
1	3	2·78	15	32·61
2	37	34·26	9	19·57
3	22	20·37	8	17·39
4	24	22·22	9	19·57
5	14	12·96	1	2·17
6	3	2·78	—	—

Table 5

Diversity of Prey Taxa
between Charr and Brown Trout.

	DAPHNIA HYALINA		BYTHOTREPHES LONGIMANUS	
	No. OF FISH	%	No. OF FISH	%
JULY	2	40	3	60
AUGUST	10	20	40	80
SEPTEMBER	7	64	4	36
OCTOBER	5	83	1	17
NOVEMBER	8	80	2	20

Table 6

Seasonal Variation of Two Species of large Cladocera Foraged by Charr.

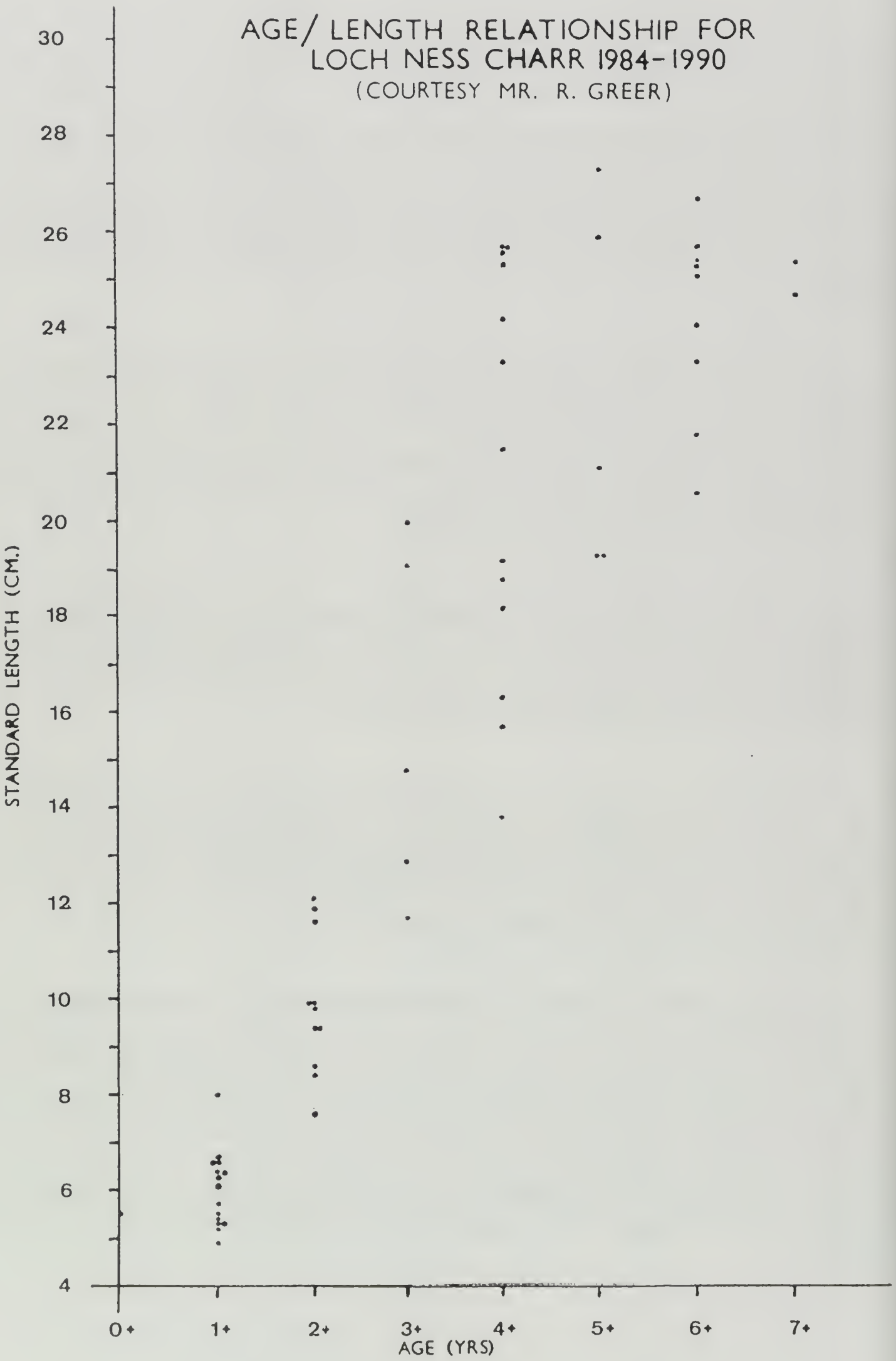
Chironomid larvae and pupae are also an important food item for Charr at certain times of the year. Although these larvae live in tubes of mud in the benthos, they are known to make extensive daily movements up into the water (Mundie, 1964; Dr. P. Cranston, pers. comm.). *Sergentia coracina,* the predominant chironomid of the profundal benthos, migrates as a 4th-instar into the water column as a means of horizontal redistribution (Brinkhurst, 1974). This is a remarkable feat, considering the depth of Loch Ness, but the larvae have often been taken in plankton hauls within the 30 m pelagic fish zone, in this late instar form. By this behaviour, chironomid larvae become available to mid-water feeding Charr.

The results in Table 1 also seem to bear witness to the fact that some of the smallest Charr (0+ age group) also have a benthic feeding mode, exploiting ostracods, copepods and caddis larvae. The smallest Charr in this study were taken in mid-water trawls, but it could be speculated that the nets swing in towards the loch walls when the towing vessel slows and drifts whilst the nets are retrieved, and thus may catch benthic sub-littoral fish.

Mr. R.B. Greer (pers. comm.) is confident, however, that the small Charr could easily move inshore and offshore within a few hours, thus exploiting two habitats, - a feeding region and a resting region. Indeed, Greer said "almost nothing is known of the 0+ year group pelagic fish in Scottish waters".

When feeding on offshore zooplankton, the small Charr show no preference in the size of large Cladocera (*Bythotrephes, Daphnia* and *Leptodora*) eaten, compared to the large Charr, although small profundal-caught Charr do appear to eat smaller benthic organisms than their larger counterparts, which are also piscivorous (Griffiths, Martin, Shine and Evans, 1993).

The pelagic Brown Trout of Loch Ness do not exploit the zooplankton to the same extent as do the Charr. Although *Daphnia* and *Bythotrephes* are exploited by 37% and over 45% respectively of the Brown Trout population, and more often than the other zooplankton species, the low numbers of these Cladocera eaten makes it appear unlikely that these organisms are subject to heavy predation by Trout. Pelagic Trout concentrate their feeding either on aerial insects, especially during the summer months (Shine and Martin, 1988), or more importantly, on fish. Table 7 shows that it is the larger Ferox Trout which exploit Charr as a food source.


AGE/ LENGTH RELATIONSHIP FOR
LOCH NESS CHARR 1984-1990
(COURTESY MR. R. GREER)
STANDARD LENGTH (CM.)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
0+
1+
2+
3+
4+
5+
6+
7+
AGE (YRS)

MONTH	No.	LENGTH (cm)	WEIGHT (g)	SEX	PREY LENGTH (cm) (EXTRAPOLATED WHERE NECESSARY)	% OF PREDATOR BODY LENGTH.
JULY	5	47·4	1016·6	F	13·0	27·4
AUG	14	38·7	650	M	11·0	28·4
	15	46·0	1045		14·5	31·5
	"	"	"		15·5	33·7
OCT	21	26·7	194·5	F	3·5	13·1
	30	29·5	308·4		5·6	19·0
	34	35·2	471·9	F	8·0	22·7
	35	34·7	501·6	F	9·0	25·9
	36	35·5	507·8	F	11·3	31·8
	"	"	"	"	7·1	20·0
	"	"	"	"	6·6	18·6
	38	40·6	715·1		5·5	13·5
	39	45·5	936·5		4·0	8·8
	"	"	"		4·0	8·8
	40	46·7	1020		14·6	31·3
	43	52·4	1674·5		10·8	20·6
	44	57·9	2033·5	F	21·5	37·1
	"	"	"	"	12·3	21·2

Table 7

Length Relationship between Brown Trout (Ferox predator) and Charr (prey) in Loch Ness

Ferox Trout have been defined as the small populations of very large and old Brown Trout present in large oligotrophic waters, with exceptional individuals exceeding 90 cm in length and 20 years of age (Campbell, 1979). In Loch Ness, the Ferox Trout lurk beneath and within the Charr layer. Indeed a Brown Trout #15, taken at 29 m in depth-marked gill nets, had eaten a Charr 33.7% of its own body weight.

In collaboration with Dr. Annie Duncan, the Royal Holloway College's pelagic survey nets were set at between 20 m and 30 m. Of 23 Brown Trout caught, eight were greater than 30 cm in length and ten had the remains of Charr within their stomachs. Of the 17 Charr taken in the same nets, ten were less than 16 cm in length, and some of the larger Trout were tangled in the nets within a few centimetres of five of the smallest gill-netted Charr, obviously caught when attempting to capture these Charr. Campbell (1979) has tabulated the feeding relationship of 17 Ferox Trout in a number of Scottish lochs, including the littoral of Loch Ness, and these show prey/predator length ratios ranging from 14.8% to 35.1%. The Loch Ness results in Table 7 are consistent with the above work, with Charr in the stomach ranging from 8.8% to 37.1% of the Trout's own body length.

Piscivorous pelagic Charr have not been observed at Loch Ness, although they have been found in the profundal Charr population. At Loch Rannoch, Walker *et. al.* (1988) recorded a benthic morph Charr containing a smaller Charr, 48% of its own body length, in its stomach.

This prompts consideration as to whether there are genetic differences between the fish populations of the pelagic zone and those of the littoral and profundal zones of Loch Ness, but special studies have revealed no genetic differences in the different zones for the Charr (Dr. Sheila Hartley, pers. comm.), nor for the Brown Trout, (Dr. A. Ferguson, pers. comm.).

The relationship between food eaten by fish, and free-swimming fauna collected in Loch Ness, shows parallels with the situation in Lake Windermere (Frost, 1977). Of the larger forms of planktonic Cladocera in Loch Ness, *Daphnia* is the most frequently abundant, with *Bythotrephes* and *Leptodora* relatively scarce and infrequent (Shine, Martin and Marjoram, 1993). Although *Bythotrephes* is much rarer than *Daphnia* in the fauna, it is consumed to a greater extent than the more abundant *Daphnia*. Even the proportion of *Leptodora* in fish guts appears high for a relatively rare species. Thus the relationship between the proportion of Cladocera in the plankton and those in the diet of fish is not a reflection of the abundance of individual species.

The selection of *Bythotrephes* and *Leptodora*, because they are large, could account for the disparity of their proportions in the fish diet and as free-swimming plankton.

Conversely, the overwhelming zooplankton species in Loch Ness are the copepods *Diaptomus gracilis* and to a lesser extent *Cyclops abyssorum*, both present all year round. Yet the incidence of copepods in pelagic guts is almost negligible, and *Diaptomus* has not been observed in the guts of the open-water salmonids, and only once as an individual in a Three-spined Stickleback, so there is a large difference between the number eaten and the supply.

Bosmina coregoni, although present in over 21% of the Charr, numbered fewer than five individuals per fish, and Brown Trout hardly exploited them at all.

If Charr, and to a lesser extent Brown Trout, actively pick out individual plankton, this suggests that a certain degree of movement occurs. Vertical migration of the fish has been studied by Shine and Martin (1988) and Shine *et. al.* (1993), but incidental evidence suggests horizontal movements as well. Brown Trout #36, a female Ferox feeding almost exclusively on Charr, contained one *Pisidium* sp. within its intestine. Of course, this presumably constituted the gut contents of a previously digested benthic Charr, but of more interest, - was it the Charr moving offshore, or the Brown Trout moving inshore, which led to the fatal encounter for the smaller fish?

Migrations do occur as winter approaches. The vertically migrating fish disappear from the open water, probably to the loch walls and littoral zone, presumably in response to the declining availability of the zooplankton, and the need to find spawning grounds. Spawning by Charr has been observed in mid-December in the littoral zone at about 15-25 m depths.

Conclusion

Judging from the various and sometimes conflicting accounts of the food of Charr in some Scandinavian waters (Dahl, 1920; Sømme, 1933a, 1933b; Schmidt-Nielsen, 1939), and then comparing these with the accounts of the food of Charr in some English lakes and Scottish lochs (Frost, 1977; Walker *et. al.*, 1988), it would appear that the Charr is an extremely opportunistic fish, preferring certain food items but adapting and adjusting its feeding habits to the particular feeding circumstances present at the time.

Table 5 supports the idea that Brown Trout are more territorial and ecologically rigid in their diversity of prey (Nilsson, 1963), whilst Charr, through their non-aggressive behaviour and shoaling habit, are well suited to living a pelagic roaming existence, easily changing from one feeding behaviour to another.

The overlap between the food of Charr and Brown Trout in the Loch Ness pelagic appears to be low, allowing the Charr to avoid severe interspecific competition with Brown Trout, and thus to occupy different feeding niches.

Finally, it is worth mentioning the likely contribution of Sticklebacks to the pelagic zone. In a recent November mid-loch trawl in the South Basin, of 115 fish captured 53 were Sticklebacks. An initial investigation of their gut contents suggests the Sticklebacks exploit small-sized *Daphnia* and the small zooplankton species - *Cyclops*, *Diaptomus* and *Bosmina*. On one occasion, at a uniform sampling depth, it was observed that the *Bosmina* sp. population declined from the north-east to the south-west end of the loch, and that *Cyclops* sp. did the opposite, i.e. increased down the loch (Shine *et. al.*, 1993).

The large number of presumed Sticklebacks in the South Basin pelagic zone may account for a disparity between *Bosmina* eaten by Sticklebacks and *Bosmina* free-swimming in the water column, if indeed Sticklebacks do exploit this cladoceran. It would also mean that the Sticklebacks could avoid interspecific competition with the salmonids within the pelagic zone. The Stickleback samples from the trawl, however, are as yet unworked.

Acknowledgments

The authors wish to thank all the volunteers of the Loch Ness and Morar Project for their efforts in collecting the fish, and Mr. R.B. Greer and Dr. Annie Duncan for the provision of nets. Some of the fish-netting work was supported by a Small Ecological Project Grant from the British Ecological Society.

The D.A.F.S. Marine Laboratory at Aberdeen provided the trawls used, and we are indebted to the crews of the Simrad demonstration vessel *Simson Echo*, the *Ocean Bounty*, and the D.A.F.S. vessels *Goldseeker* and *Calanus*, for the work done and material supplied. In particular, Dr. Richard Ferro of D.A.F.S. supervised the *Goldseeker* operation in 1988, and we thank the Director of the Marine Laboratory, Dr. A.D. Hawkins, for his support in making the operation possible.

Ms. Jane Harper conducted many of the initial dissections, Mr. R.B. Greer worked the otoliths for Charr ageing, and Dr. Sheila Hartley and Dr. Andrew Ferguson are continuing work on the genetics of Brown Trout and Charr.

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Received May 1993

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LARGE AND SMALL ORGANISMS DETECTED IN THE OPEN WATERS OF LOCH NESS BY DUAL-BEAM ACOUSTICS

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Introduction

A great deal of what is already known about the biology of Loch Ness derives from Sir John Murray and Laurence Pullar's *Bathymetrical Survey of the Scottish Fresh-Water Lochs* (Murray and Pullar, 1910) and from Dr. Peter Maitland's studies in 1977-80 on the ecology of Scotland's five largest lochs (Maitland, 1981). Although he recorded seven species of fish in Loch Ness, Maitland suggested that only three were predominant in the open waters of the loch - Charr *Salvelinus alpinus*, Brown Trout *Salmo trutt*a and Salmon *Salmo salar* - all largely in the top 30 m. More recently, Shine and Martin (1988), of the Loch Ness and Morar Project, provided some evidence of the presence of fish in the profundal zone by netting Charr from 200 m deep with the profundal bivalve, *Pisidium conventus*, in their guts.

With the advent of commercially available scientific echo-sounders in the 1980s, the study of fish in large deep lochs was suddenly made much easier. These instruments applied the physics of sound to be able to discriminate between 'fish' and other targets reflecting back sound echoes, to 'size' the echoes, and to count them with confidence in a known volume of water. By various means, the position of the 'fish' target in the sound beam could be determined. The volume of water which could be sampled for fish targets was very large indeed, - in the May 1992 survey it was about 5% of the volume of the pelagic region of Loch Ness down to 100 m depth.

Plate 1

Inside Mr. R. Bremner's Dory - 17, showing the acoustic gear in operation whilst underway.

From left to right: Toshiba 5200 microcomputer on top of the BioSonics Model 105 dual-beam echo-sounder, the Model 171 tape recorder interface, and the Model 171 chart recorder. On top are the Tektronix 222 oscilloscope for immediate viewing of targets, and the Technics SV260 data audio tape recorder for recording sonar input.

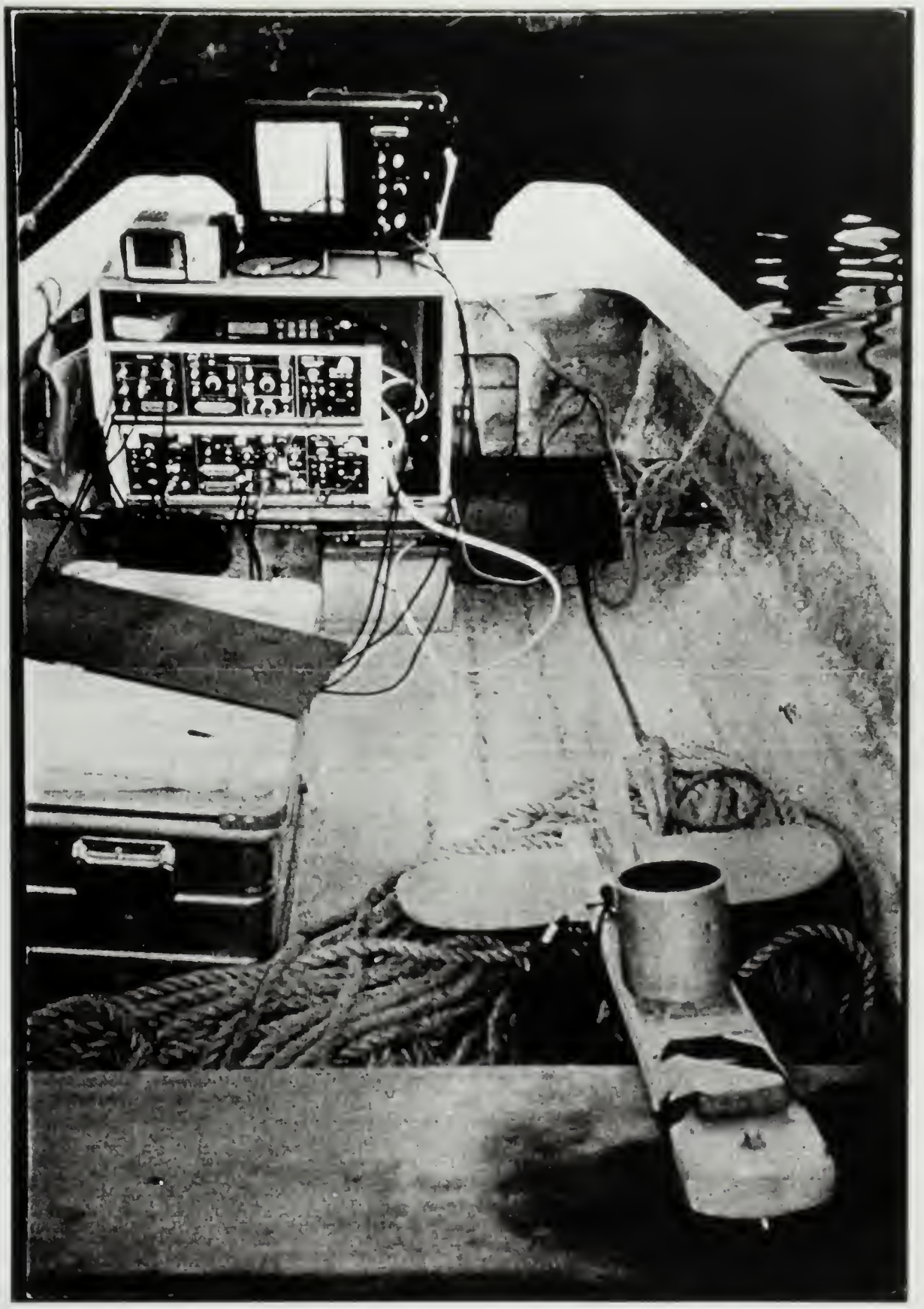

Plate 2

A 420 kHz circular dual-beam transducer 6/15° attached to a towing body.

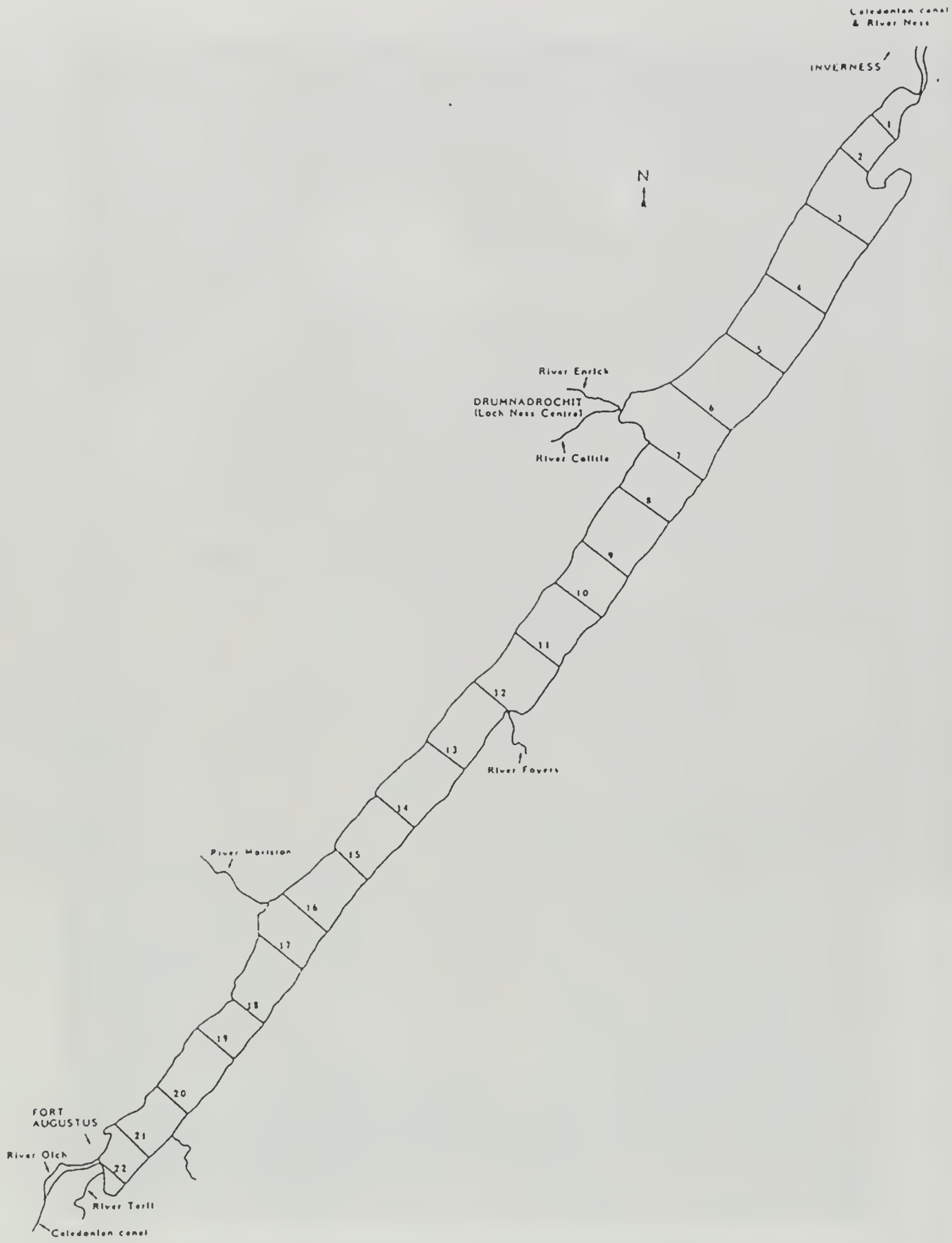

Figure 1a

Map of Loch Ness (35 km long; 1.5 km wide; 230 m deep; 7,452 million m^3 volume), showing the 22 transects sampled in May 1991.

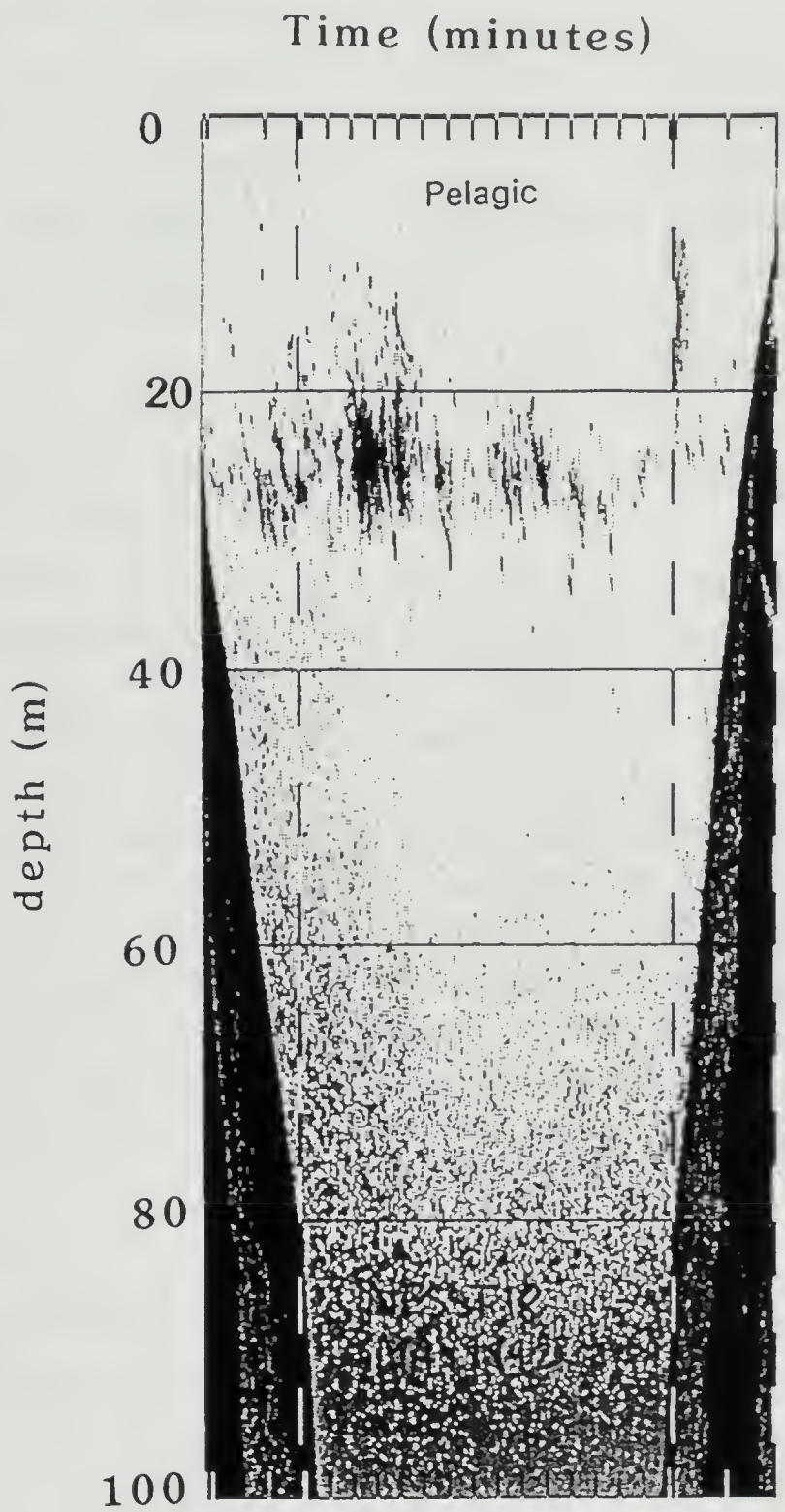

Figure 1b

A typical chart record of a transect, showing the position of the pelagic acoustic run with its scattering layer.

When Royal Holloway University of London acquired a BioSonics Model 105 Dual-Beam Echo-Sounder, we used it to carry out several preliminary acoustic surveys in Loch Ness for the Loch Ness and Morar Project, and were thrilled to find that it could be used to provide an instantaneous acoustic picture of the horizontal and vertical distributions of the fish populations, as well as size composition, in some two days of field work. The present account outlines some of the difficulties encountered, but there can be no doubt about the power of this new tool in the hands of ecologists.

Acoustic Methods

Of the three preliminary acoustic surveys carried out in Loch Ness (May 1991, October 1991 and May 1992), the May 1991 survey was the best, and it is this survey which will be most discussed. Figure 1 shows the position of the transects which were surveyed during two consecutive days. Each transect was surveyed by three runs, one pelagial in 200 m of water and two runs over the basin walls (down to 70 m depths), in which different ping rates were applied, 2.0 pings per second in the deeper water and 5.0 pings per second in the shallower depths.

The BioSonics Model 105 Echo-Sounder was operated from a Dory-17 boat (Plate 1) with a 420 kHz transducer suspended from a towing body (Plate 2) at 2.0-3.0 m depth and beaming vertically down to 70-100 m, at which depth the signal-to-noise ratio became too low. Pulse durations used were 0.8 ms and single targets were identified by selection criteria.

The instrument was calibrated in May 1991, by using a long-life ping-pong ball (-42 dB) suspended below the transducer, and re-calibrated later using a tungsten-carbide standard target (-43.7 dB). The noise thresholds applied were generally very low in depths down to 50 m, thus allowing us to record acceptable targets down to -81 dB.

The size and densities of single targets were processed using the BioSonics Echo-Signal Dual-Beam Processor (ESP_DB), whilst the total acoustic biomass was determined by the BioSonics Echo-Integration Processor (ESP_EI). The size analysis of single targets showed a predominance of very small targets, and we made an attempt to discriminate between these tiny targets (or scatterers) and real fish targets by using two kinds of integration strata simultaneously. The two strata were the primary, which integrated all targets from -81 dB to the largest target (fish plus the scatterers of the scattering layer), and the secondary strata, which integrated those targets larger than -55 dB (fish only).

To convert echo-integrated acoustic biomass from volts squared to the number of fish individuals requires a scaling factor, which is influenced by the size of the average back-scattering cross-section of the targets. This was $2.974*10^{-8}$ m^2/individual for the scatterers at all depths (0-50 m) and $1.84*10^{-5}$ m^2/individual for fish targets in different depths. These values result in widely differing scaling factors (Figures 6 and 8).

The biomass of the fish targets was calculated using the echo-integrated squared voltages divided by a mean back-scattering cross section of $4.27*10^{-4}$ m^2/kg. This scaling factor comes from stunned Trout of various sizes exposed in front of a 420 kHz transducer (unpublished data).

Results and Discussion

Dual-Beam Echo-Counting and Fish Sizing

Despite the reputation of Loch Ness, the densities of pelagic targets of the size of fish were surprising low, if one takes a fish target to be >-55 dB or larger than 4.0 cm length (Love, 1971). When the whole size composition of acoustic targets in the open water of the entire loch is considered, the undoubted fish targets contributed a very small proportion (Figure 2). In the shallower, rather sheltered and more productive Urquhart Bay, on the other hand, the proportion contributed by fish was strikingly greater. The average acoustic size of fish in open water of the loch was -47 dB, which, according to Love (1971), is equivalent to a length of 8.5 cm.

In every transect, many hundreds of scatterer targets were detected (Figure 1b) whose target strength ranged from -79 dB to -73 dB in 1991 (Figure 2) and -74 dB to -70 dB in 1992 (Figure 3), concentrated in the depths between 12 m and 30 m. No-one yet knows what these are, although they are most likely to form the scattering layer described by Shine and Martin (1988).

For May 1992, Figure 4 provides a three-dimensional diagram of the frequency of target strengths of all targets in every transect from north to south. As above, this figure also shows the small proportion of fish targets and the consistency of the peak target throughout the entire 23-mile loch, but with a tendency towards an increased number of targets per transect from north to south. This finding corresponds to earlier acoustic records of increased acoustic counts in the South Basin, as determined by the simultaneous deployment of seventeen vessels during Operation Deepscan in October 1987 (Shine and Martin, 1988).

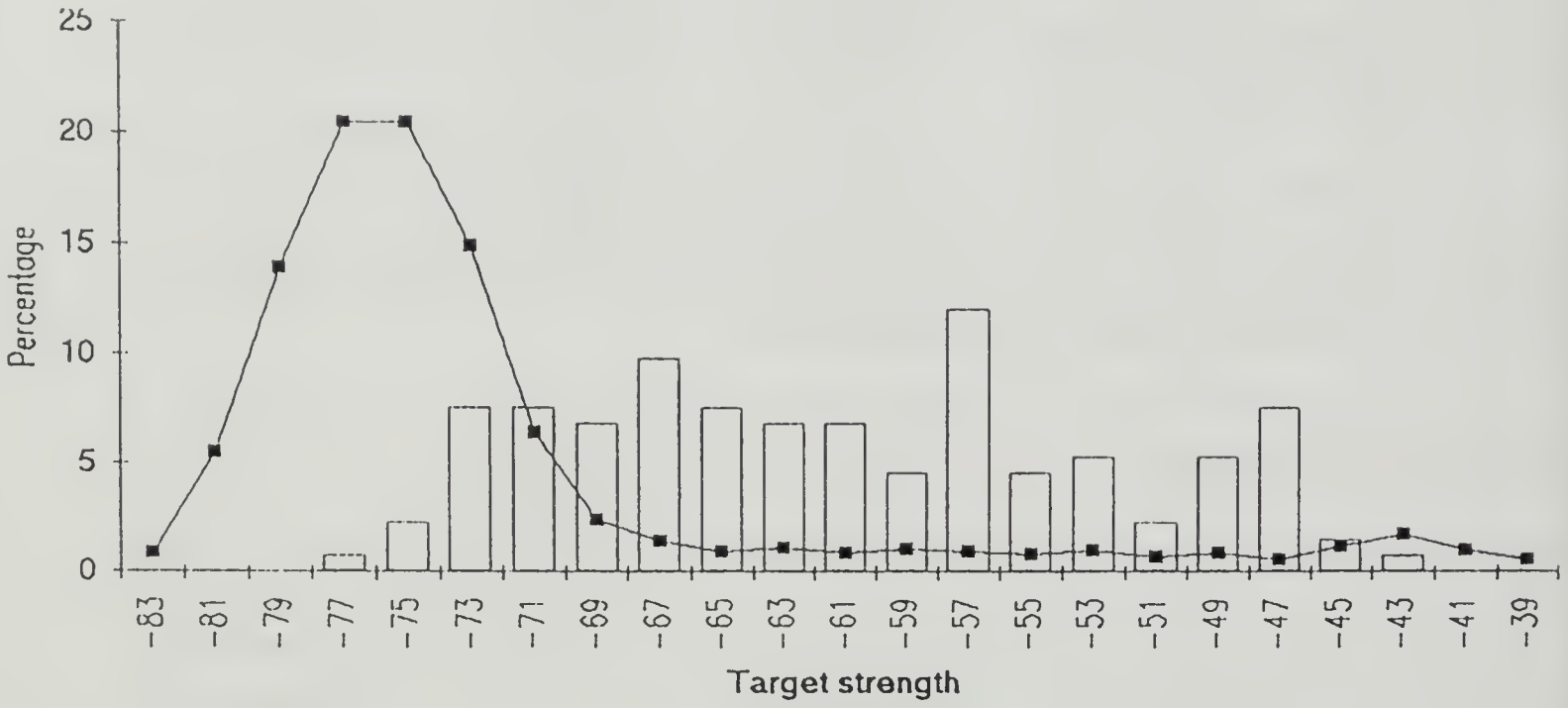

Figure 2

Loch Ness May 1991: Target strength frequencies in the open water compared with those in Urquhart Bay.

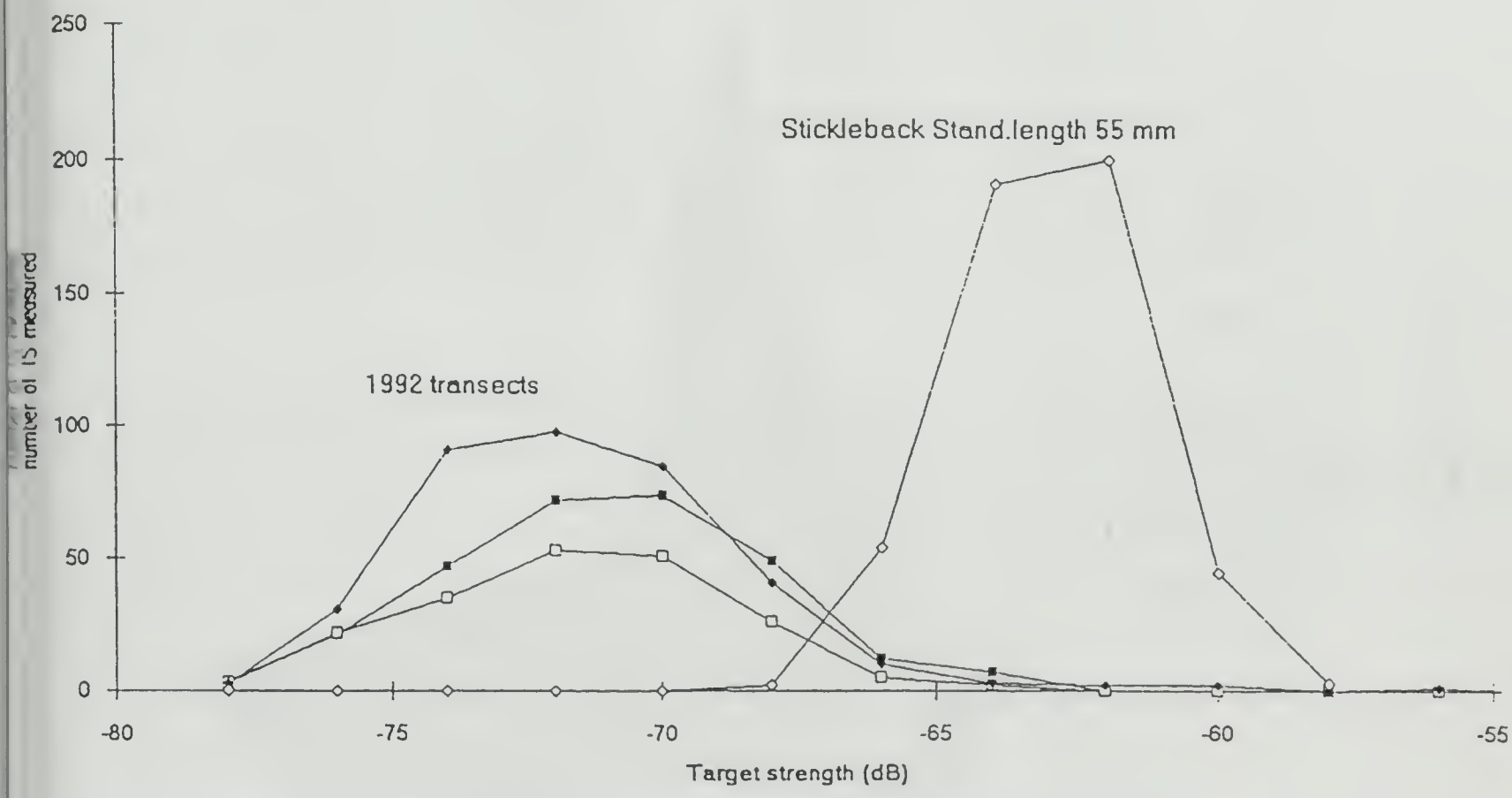

Figure 3

Loch Ness May 1992: Target strength frequencies in the pelagic scattering layers of three 1992 transects compared with the target strength of a 55 mm Stickleback.

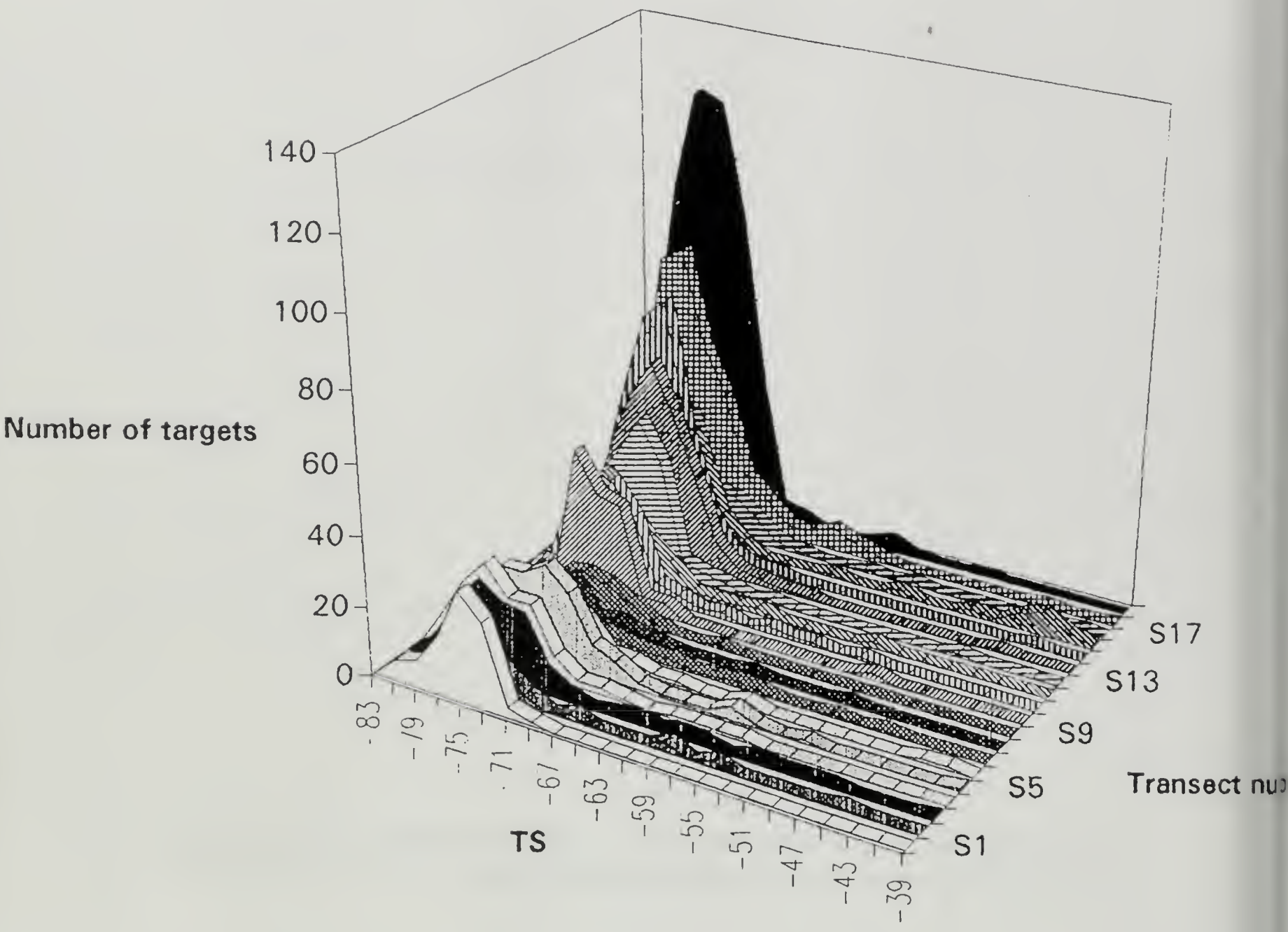

Figure 4

Loch Ness May 1991; A three-dimensional plot of target strength frequencies in the 22 transects surveyed.

Figure 3 compares the target strengths of the loch's scatterer targets with a 55 mm Three-spined Stickleback *Gasterosteus aculeatus* suspended in the scattering layer itself. Even such a small fish, were it in the full pelagial, would be a much bigger target than the scatterers. It is known that young Charr inhabit the open water, since in November 1992 Charr as small as between 3.5 mm and 7.0 mm were caught by mid-water trawl (Shine, Kubecka, Martin and Duncan, 1993). However, sampling the scattering layer depths by ichthyo-plankton tow net (1.0 m diameter; 1.0 mm mesh size) in May 1992 caught just one Lamprey *Lampetra fluviatilis* larva, one small Charr and chironomid pupae at densities of about 0.1 individuals/m^3.

Larger targets are also present in Loch Ness; between 67 m and 85 m depth of transect 17 a large shoal of large targets was detected (Figure 5). The shoal was so dense that most of the targets were not single (Figure 5a). Tracked single targets at the edges of the shoal are shown in Figure 5b, and these had target strengths of about -35 dB to -24 dB, probably with a maximum length of one metre! Such compact shoals of very large fish might quite well have caused earlier mis-identification of Monsters.

Echo-Integrations for Biomasses

Figure 6 shows a marked trend of increasing fish density from north to south. The same trend can be seen when the acoustic density is expressed as fish biomass (Figure 7). The density distribution of total targets (>-81 dB or greater) was calculated by applying one scaling factor, that for small scatterers, since these were much more numerous than fish targets; the density distribution of these total targets also showed a similar north-south trend, but much less pronounced (Figure 8).

Simple subtraction of fish volts squared from total volts squared was too crude a process for estimating the density of the loch's scatterers. This is probably caused by the highest densities of scatterers appearing as multiple targets of voltage large enough to be taken by the Echo-Signal Processor as fish targets, something which occurs more frequently in the more southern transects. The bias caused to estimates of fish abundance by identifying and incorporating small scatterers as multiple targets is not too serious, because of their very small 'acoustic weight', and Figure 7 can be accepted as an upper estimate of fish abundance down to 60 m depth in transects along the loch.

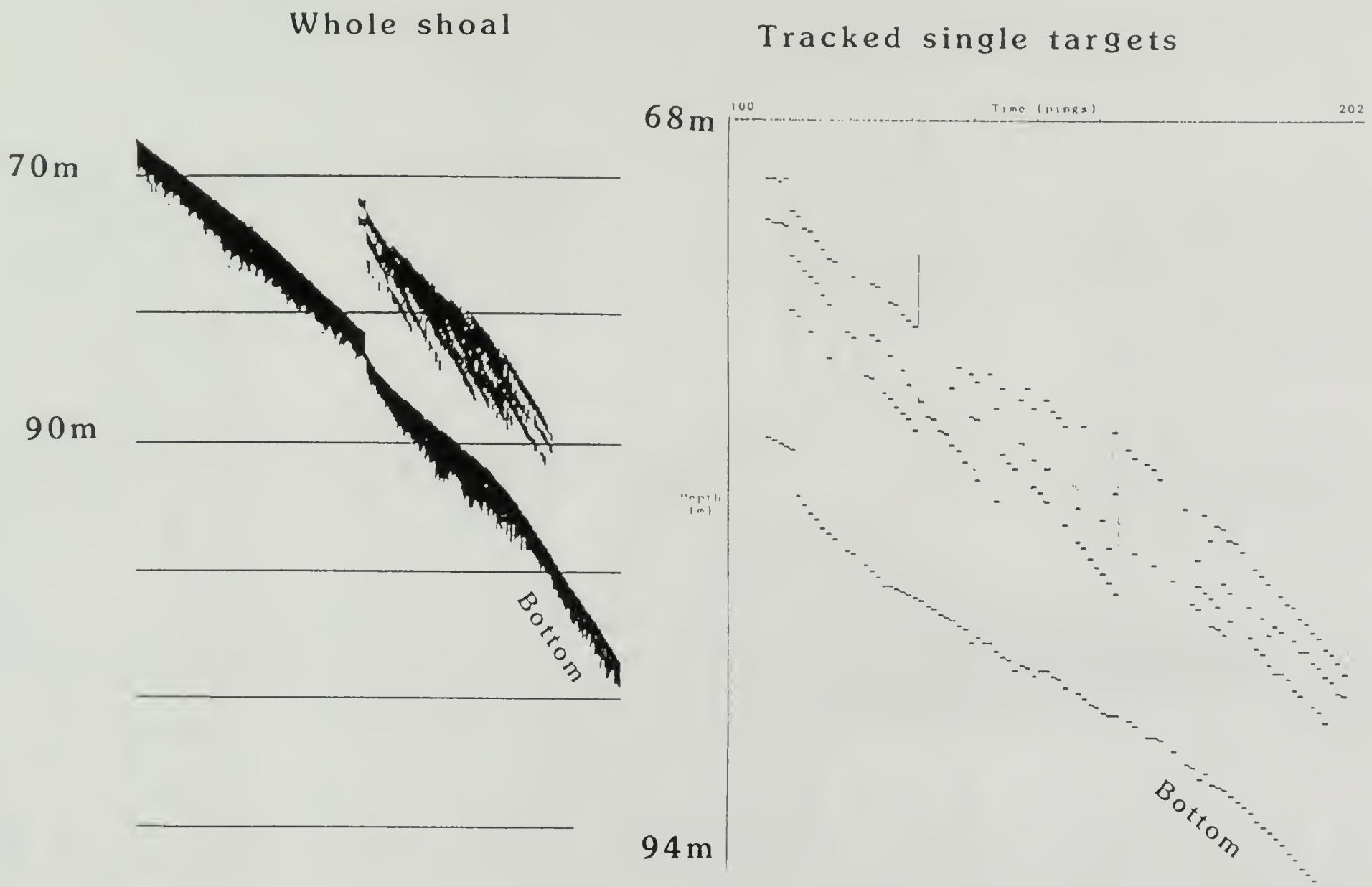

Figure 5

Loch Ness May 1991: A large dense shoal of targets (a) recorded near the bottom between 67 m and 85 m deep in transect 17. The target strengths of single targets at the margins of the shoal (b) were estimated to range between -35 dB and -24 dB (i.e. large targets of about 1.2 metres length).

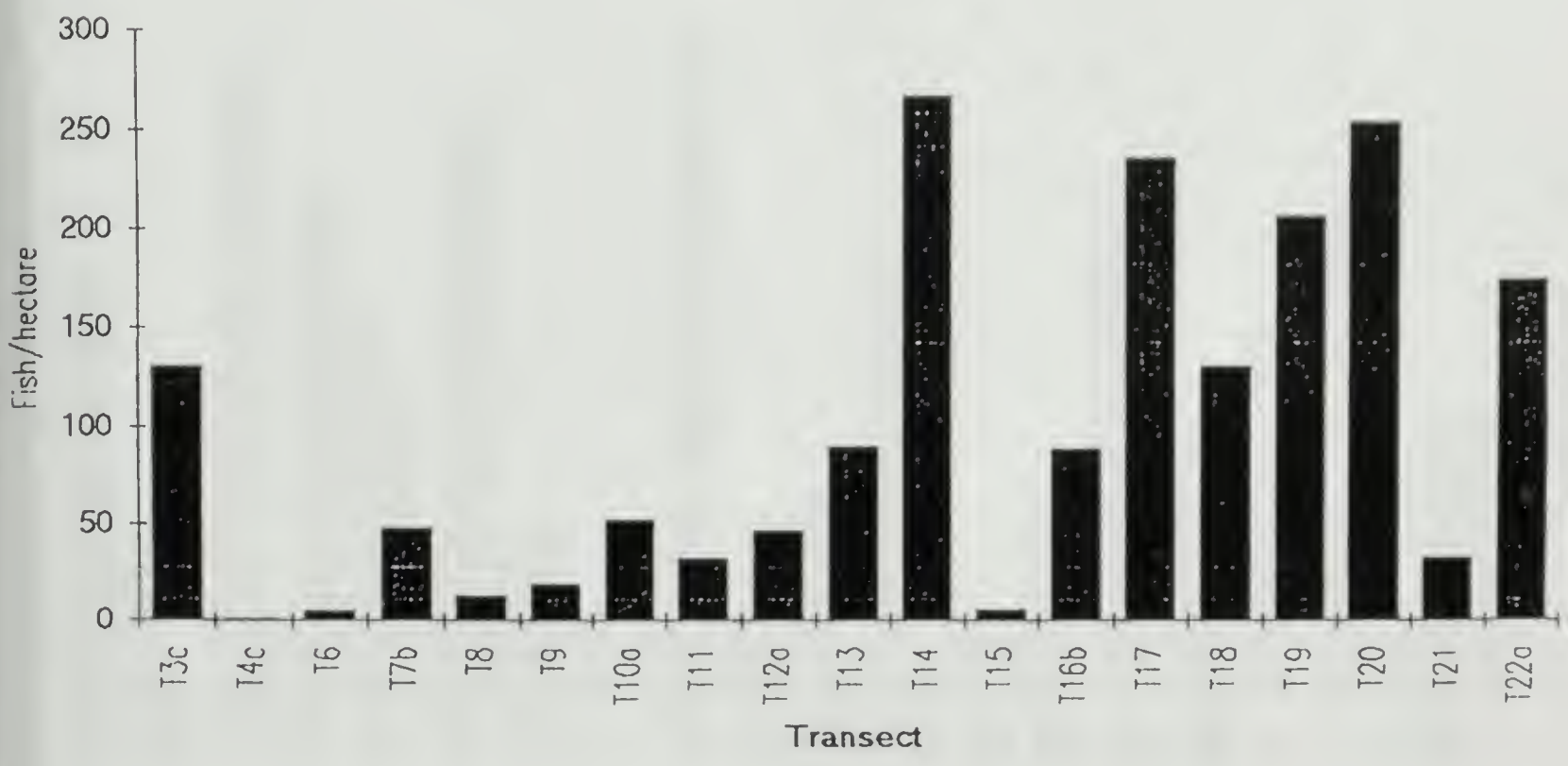

Figure 6

Loch Ness May 1991: Horizontal distribution of fish target densities (>-55 dB) in the open water from north to south.

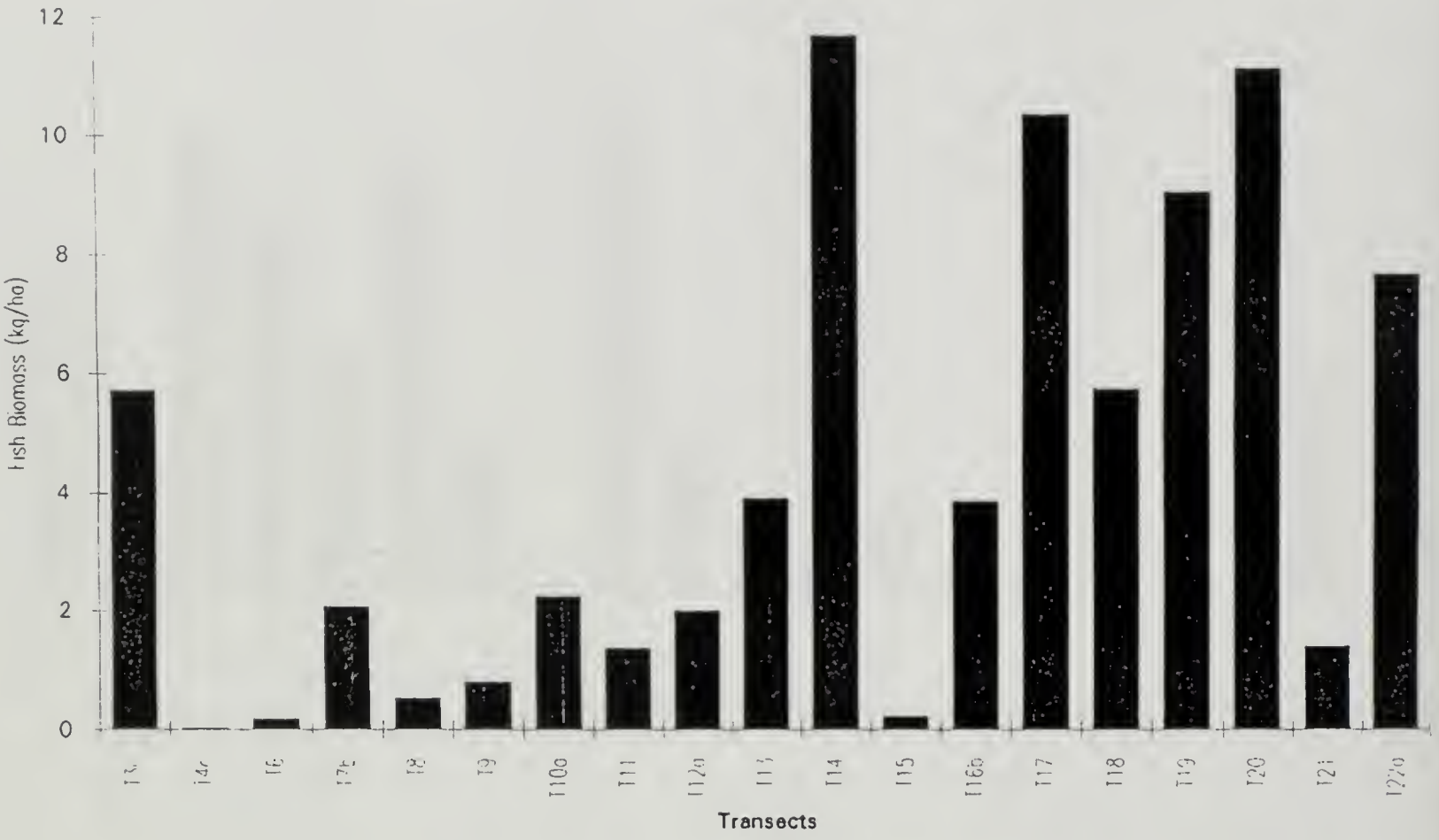

Figure 7

Loch Ness May 1991: Horizontal distribution of fish biomasses in the open water from north to south.

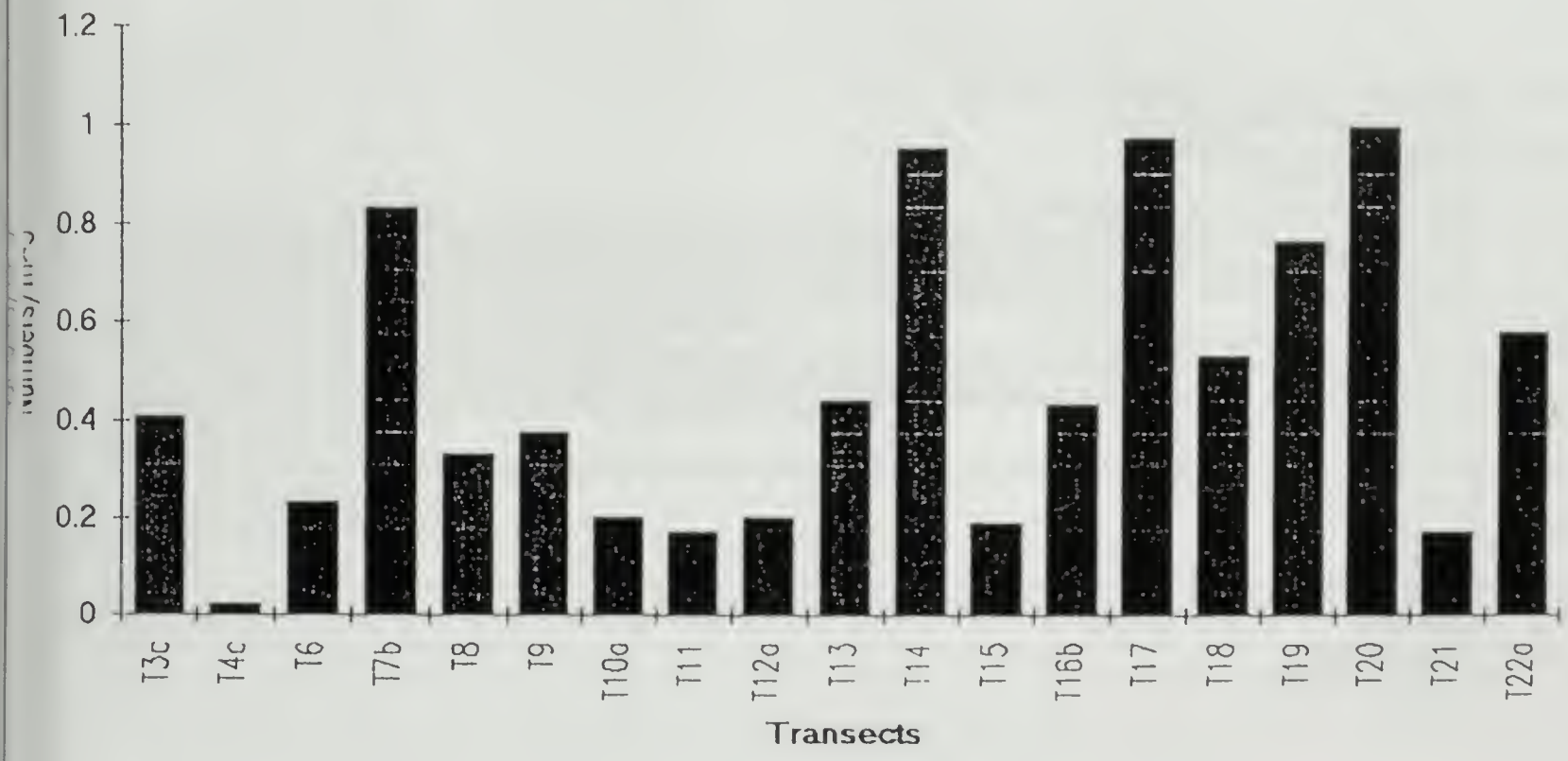

Figure 8

Loch Ness May 1991: Horizontal distribution of total target densities (>-81 dB) in the open water from north (transect 3c) to south (transect 22a).

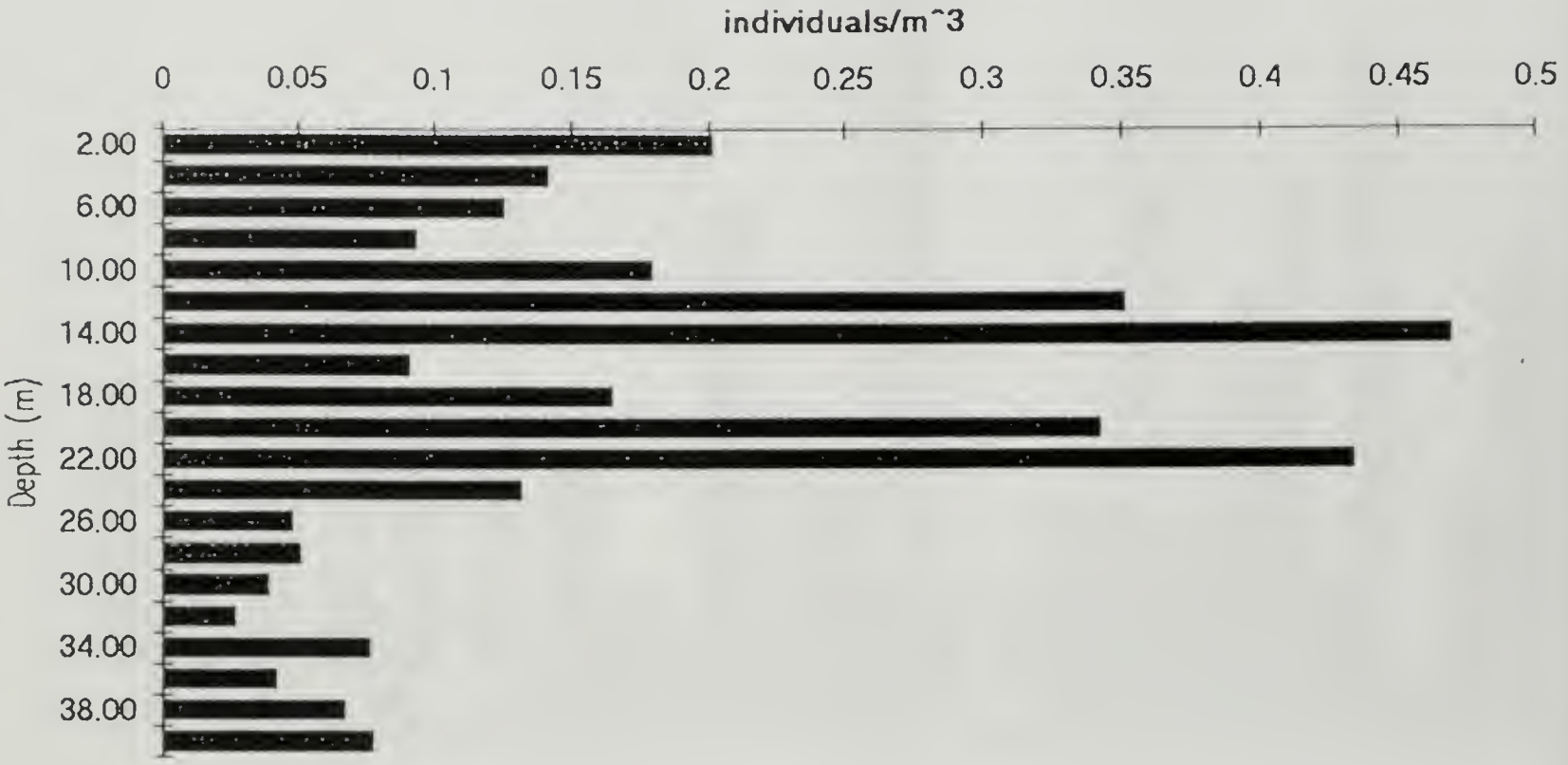

Figure 9

Loch Ness May 1991: The average depth distribution of 'scatterer' densities (-75 dB to -55 dB).

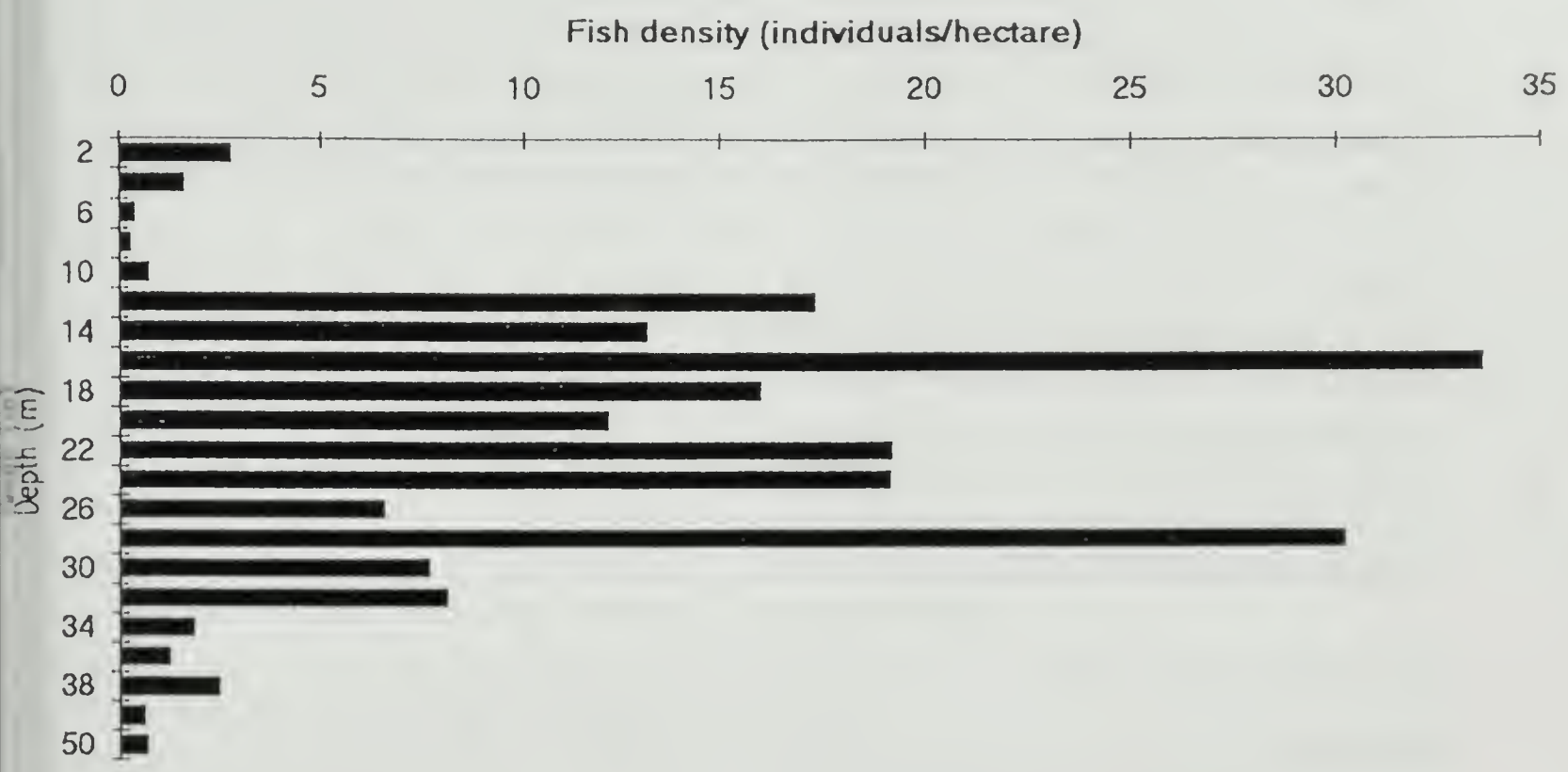

Figure 10

Loch Ness May 1991: The average depth distribution of fish targets (>-55 dB).

An average depth distribution of the so-called 'plankton densities', arbitrarily defined as targets between -75 dB and -55 dB, is illustrated in Figure 9, and shows doubled densities between 12 m and 22 m. These densities were calculated as the difference in volts squared between total V^2 and fish V^2 and converted to numbers/m^3 by a 'scatterers' scaling factor. Densities of fish targets (>-55 dB), given as number/ha for each 2.0 m depth stratum (Figure 10), are also concentrated between 12 m and 28 m, with few in the top 10 m water layers. These were scaled by the same back-scattering cross section at all depths. In the absence of better information on the identity and target strengths of the small scatterers and the smaller pelagic fish, we cannot fully exploit the flexibility of BioSonics software to discriminate further between these two classes of acoustic targets in Loch Ness, or to better calculate their relative biomasses. The actual densities shown in Figures 9 and 10 should be considered to be relative rather than absolute, because in each class of targets the span in acoustic size is very great (the dB scale is a logarithmic one), so that the use of an average back-scattering cross section can only be crude.

Summary

1. The entire 23-mile length of Loch Ness was surveyed acoustically in May 1991, in October 1991 and in May 1992 using a BioSonics Echo-Sounder with an operating frequency of 420 kHz. Detailed results are given of the May 1991 survey, since this was the best and involved acoustic runs over the pelagic region (200 m depth) in 22 transects.

2. Acoustic densities of fish targets (>-55 dB) in the pelagic region of the loch were low, whereas there were hundreds of small scatterers (-79 dB to -73 dB). The average acoustic size of fish was -47 dB. The mean density (±SD) of fish targets in the loch pelagial was 97 ± 91 fish/ha down to 60 m depth. The mean biomass of these fish was 4.23 ± 4.00 kg/ha, giving a rough average individual size of 43.6 gm.

3. The density per transect of total targets and of fish targets increased from north to south.

4. The average loch depth distribution of both scatterers and fish targets peaked at between 12 m and 22 m for the former and between 12 m and 28 m for the latter.

Acknowledgements

We should like to express our grateful thanks to Royal Holloway University of London and the National Rivers Authority for permission to use the sonar systems. We should also like to thank the Loch Ness and Morar Project team for our work-time on their boat *Ecos*, and for their hospitality during our visits; also Mr. R. Bremner of Drumnadrochit for the loan of his splendid Dory-17 boat in May 1991.

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Received May 1993

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SPATIAL DISTRIBUTION AND DIURNAL MIGRATION OF THE PELAGIC FISH AND ZOOPLANKTON IN LOCH NESS

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Loch Ness and Morar Project

Introduction

The first suggestions of an off-shore population of Charr *Salvelinus alpinus* in Loch Ness were made as a result of echo-sounding by Dr. P.F. Baker (Baker and Westwood, 1960). Echo-sounder transects were also made as a part of the Institute of Terrestrial Ecology's multi-disciplinary survey during 1977-80 (Maitland, 1981).

Throughout the 1980s, the Loch Ness and Morar Project conducted a pelagic programme of qualitative echo-sounding, gill-netting and trawling, designed to reveal the basic distributions of fish within the water column and along the axis of the loch (Shine and Martin, 1988). Species taken by pelagic gill-netting and trawling consist mainly of Charr, with some Brown Trout *Salmo trutta* and, particularly in the southern basin, Three-spined Sticklebacks *Gasterosteus aculeatus*. From 1988 onwards, more quantitative acoustic methods have been applied, which have improved our understanding of the distribution, numbers, biomass, and diurnal behaviour of the fish population. Observations have also been made of the vertical and horizontal distribution of zooplankton.

Most of these exercises were carried out as part of 'Operation Echo', a series of collaborations with the Simrad Company and the Marine Laboratory of the Department of Agriculture and Fisheries (D.A.F.S.) at Aberdeen. Simultaneous surveys were also carried out by the Hydroacoustic Unit from Royal Holloway University of London, and are described separately (Kubecka, Duncan and Butterworth, 1993).

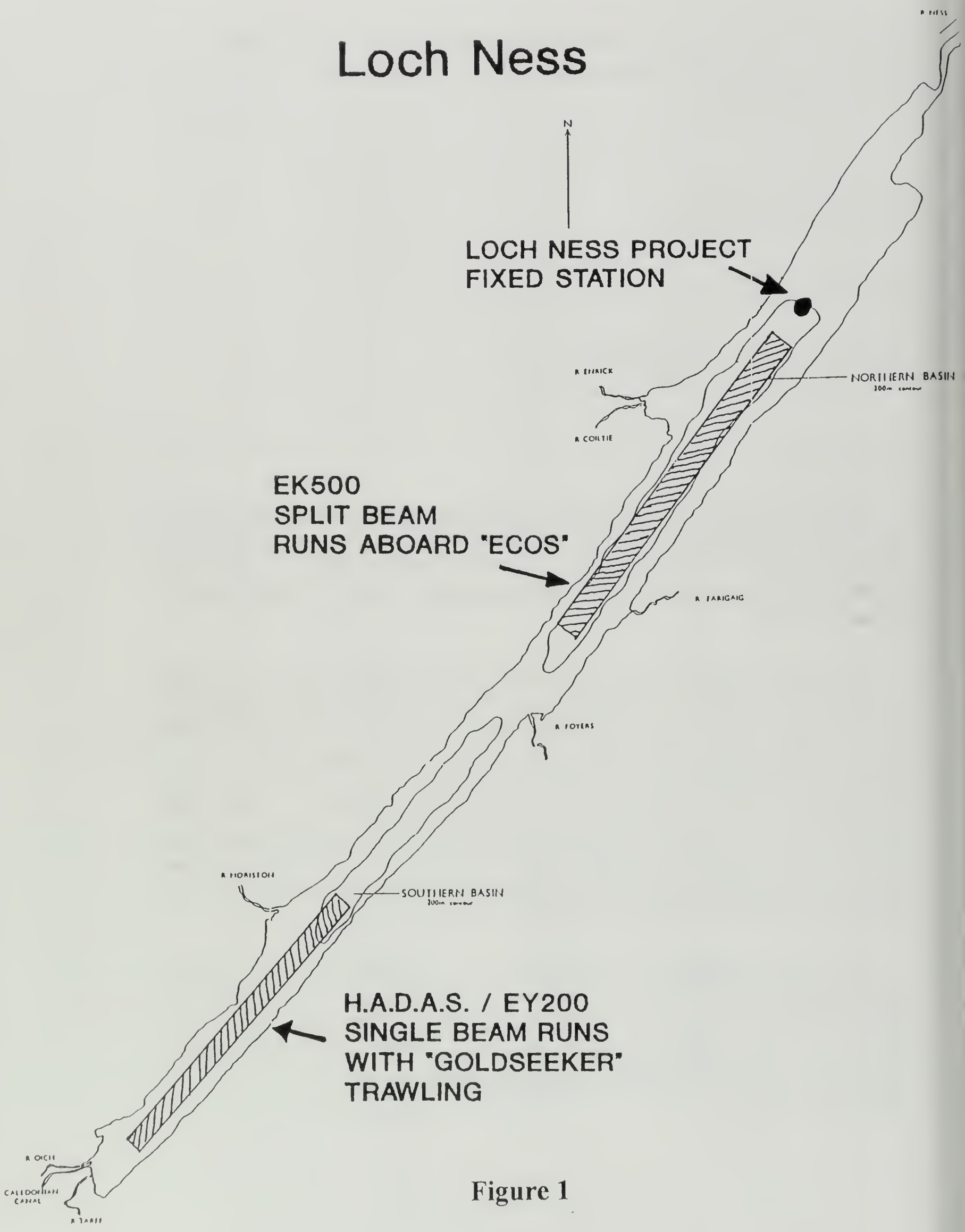

Loch Ness
N
LOCH NESS PROJECT
FIXED STATION
R. ENRICK
NORTHERN BASIN
200m contour
R. COILTIE
EK500
SPLIT BEAM
RUNS ABOARD "ECOS"
R. FARIGAIG
R. FOYERS
R. MORISTON
SOUTHERN BASIN
200m contour
H.A.D.A.S. / EY200
SINGLE BEAM RUNS
WITH "GOLDSEEKER"
TRAWLING
R. OICH
CALEDONIAN CANAL
R. TARFF

Figure 1

Methods

The data presented here has been obtained from several sources: from a fixed station established on deep-water moorings, and from various longitudinal and transverse runs with a variety of vessels (Figure 1).

Gill nets, ranging in mesh size (stretched diagonal) from 30 to 90 mm, have been deployed from the fixed station to depths of over 30 m.

Most trawling was carried out in 1988 by the D.A.F.S. trawler *Goldseeker,* using a 'sprat' trawl with a 12 mm codend. The trawl was towed at 20-30 m depth at 2.0 - 2.5 knots with a vertical mouth opening of approximately 6.0 m. Depths were established by a Simrad Trawlink acoustic system. There were four hauls, totalling four hours of trawling.

In November 1992, material was made available from a large trawl undergoing configuration trials by D.A.F.S. aboard the research vessel *Calanus.*

Plankton observations are based for the most part upon vertical hauls at 6.0 m increments using a closing plankton net with a 28 cm diameter, one metre in length with a 0.25 mm mesh size. Hauls were taken around mid-day and midnight. Numbers are expressed per cubic metre, with no allowance for any net factor. The hauls presented for 1983 were taken with a 31-litre Patalas water sampler.

Longitudinal results are from the Royal Holloway Clarke-Bumpus sampler (15 cm aperture) towed at 20 m depth for distances of one nautical mile, separated by intervals of one nautical mile.

A Focal Industries Optical Plankton Counter, model OPC-IT, was used in 1990 to investigate particles within the scattering layer and water column. This had a sampling aperture of 3.0 x 22 cm and a 640 nanometer light source with beam dimensions of 0.4 x 2.0 cm.

Particles were detectable from 0.25 mm to 2.0 cm, and counts were made by towing over one minute intervals at depth increments through layers detected acoustically. A D.A.F.S. high-speed plankton net was attached to the towed body, and depths were measured using a Simrad H.P.R. 310T transponder.

Temperature structure was measured by a variety of instruments, ranging from a Windermere Profiler to a Lowrance single thermistor on a depth-marked wire.

Acoustic Methods

Most fixed station observations were made using conventional chart-recording single beam echo-sounders. A Lowrance X-16 (50 kHz) was used from the fixed station in the North Basin in 1991 and 1992. This has the facility to reduce paper speed, to the extent that one hour could be represented by 2.0 cm of chart, thus permitting monitoring over several days to be presented in a manageable form.

Much of the basic distribution of targets within the water column may be overviewed in this way. There is, however, a difficulty in quantifying the numbers of fish and their sizes. Even echo-sounders capable of target strength measurement with a single beam cannot quantify the true target strength, since a small fish in the centre of the beam may appear stronger than a large fish off axis. Acoustic surveys using echo-integration therefore required scaling factors derived from fish catches.

In the 1980s three new acoustic methods capable of *in situ* target strength assessment were refined, and between 1988 and 1992 the Project was fortunate to participate in the first practical use of these systems in Britain's freshwaters.

All three systems exploit sophisticated software processing, in particular to apply 'single fish echo criteria'. This criteria rejects echoes below a given noise threshold and those of short length likely to be noise. In addition, echoes larger than the criteria at various points along the peak are classified as multiple targets. All systems utilise echo-integrators to total the acoustic biomass, while relating the measured target strength distribution to this. The differences lie in the way this target strength distribution is obtained; detailed descriptions and comparisons of the three systems are given below:

1. H.A.D.A.S. Hydroacoustic Data Acquisition System.
   See Craig and Forbes (1969). Figure 2a.

This is an indirect statistical method for use with a single beam echo-sounder. Developed by Dr. Torfin Lindem of Oslo University, the software package utilises the algorithm proposed by Craig and Forbes (1969) to remove the effect of the beam pattern from the received echoes.

In general, the echoes are divided into classes, with the strongest assumed to come from the largest fish in the centre of the beam, with the second strongest coming from the second largest fish in the centre, together with the largest fish in the first off-centre classification.

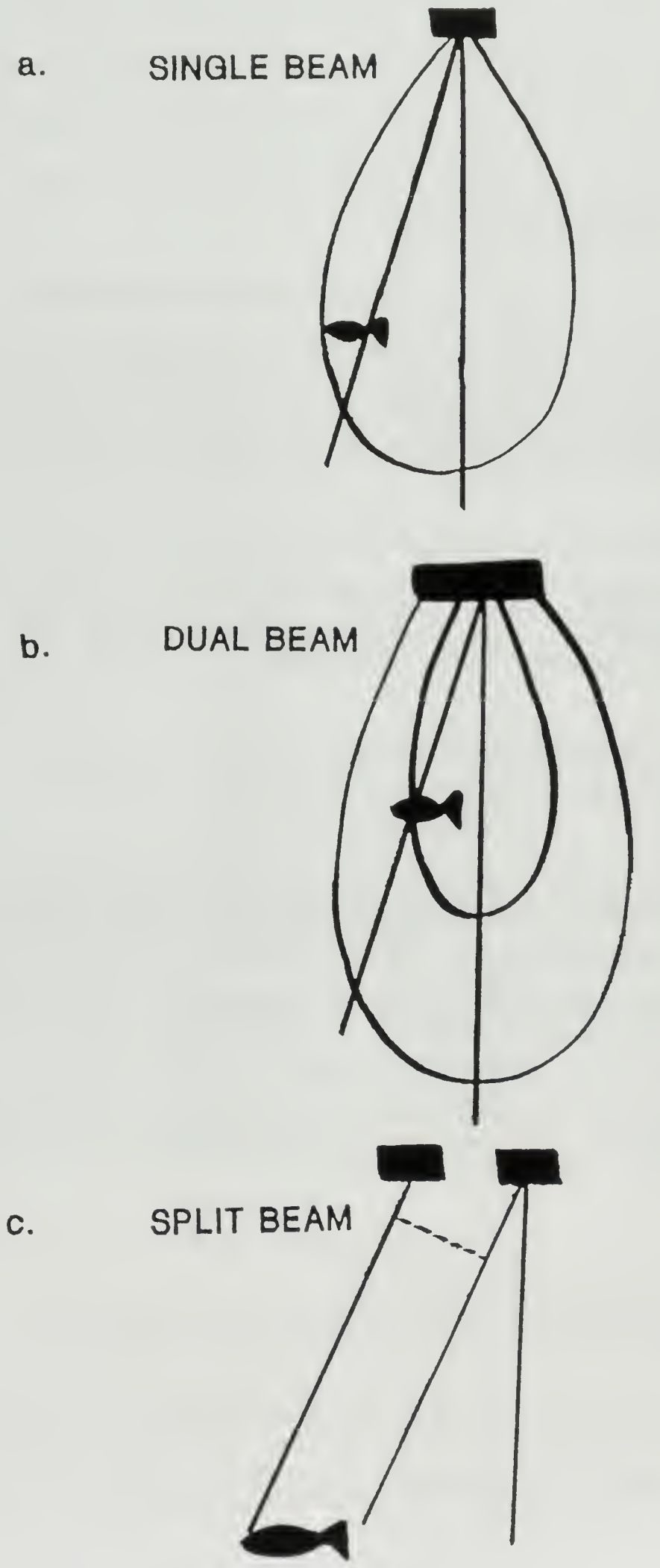


Figure 2: Acoustic Target Strength Measurement

This process is applied progressively throughout the various size classes, and therefore requires a large number of echoes (1,000+) and a good percentage of targets passing the single fish criteria. The proportions between resolved single fish and multiples are established through echo-integration, thus allowing the total density to be calculated. The equipment was originally developed for the Simrad EY-M sounder, and has been used in a number of surveys (Jurvelius, Lindem and Louhimo, 1984; Hartmann *et al.*, 1987).

On 24th July 1988 Dr. Lindem brought an advanced version of H.A.D.A.S. to Loch Ness, where it was linked to a Simrad EY200 sounder (49 kHz) calibrated with a copper sphere. The equipment was mounted with an in-hull transducer aboard the Simrad vessel *Simson Echo,* and two runs of approximately 5.0 km were made in the South Basin between Fort Augustus and Invermoriston.

The first run was by day at 15.00 hrs and the second at dusk (20.00 hrs). Single fish resolution was mostly 90-100% and never below 70% By day 4,790 single fish echoes were resolved, and by night 1,600. Trawling was carried out simultaneously in the same area by the *Goldseeker.*

2. The Dual Beam Method (Biosonics Inc.).
   See Ehrenberg (1978); Traynor and Ehrenbrg (1979). Figure 2b.

This is a direct acoustic method of target strength determination, transmitting pulses on a narrow beam element and receiving them on both this transducer and through a wider surrounding beam. The ratio between the signals received by the two beams provides the off-axis angle of the target. The Royal Holloway Hydroacoustic Unit brought a Biosonics 105 Dual Beam sounder to the loch in May 1991, October 1991 and May 1992. During the May visits the equipment was used simultaneously with the EK500 Split Beam equipment described below. The Dual Beam findings are described in an accompanying paper by Kubecka *et al.* (1993).

3. The Split Beam Method (Simrad EK500).
   See Bodholt, Nes and Solli (1988); Ehrenberg (1979). Figure 2c.

This is another direct method of *in situ* target strength assessment, and relies upon the phase difference of echoes received by separate elements of the transducer, thus locating the target within the beam and compensating accordingly.

The Simrad EK500 utilises four transducer elements, and was first used at Loch Ness with a hull-mounted transducer aboard the *Simson Echo* in July 1990. Subsequently it was installed with both 38 kHz and 120 kHz transducers rigged at 1.0 m depth aboard the Project vessel *Ecos* in May 1991 and 1992.

In May 1992 a series of 0.5 nautical mile runs, totalling 10.5 n-miles, were made in the North Basin both by day and at approximately midnight. The distributions quoted are the mean of these runs.

On 24th May a length run was made along the axis of the loch. The EK500 results are produced through a colour printer which tabulates target strength distributions within chosen depth layers. The number of accepted single fish echoes is also recorded, together with the SA (area back-scattering coefficient) or integrated value expressed in m^2 per n-$miles^2$.

In the estimation of fish densities the sigmas (linear values of back-scattering cross-section for individual fish) of targets in the logarithmic dB scale are calculated thus:

$$\sigma = 4\,\pi\,(10.\ TS/10)$$

Where TS is target strength.

The percentage of sigmas per target strength group is then divided into the SA to give fish per n-$mile^2$ and converted into fish/ha.

Where fish lengths are suggested they are based upon the formulae of Lindem (1984):

$$TS = 20\ \text{Log}\ L\text{-}68 \quad \text{for small fish}$$

$$TS = 20\ \text{Log}\ L\text{-}67 \quad \text{for larger fish}$$

Where L is fish length in cm.

On occasion, Love's (1977) empirical formula is also used:

$$TS = 18.4\ \text{Log}\ L\ \text{-}1.6\ \ \text{Log}\ F\ \text{-}61.6$$

Where L is fish length in cm and F is acoustic frequency in kHz.

Results

Fish

Figure 3 provides a backdrop to the summer vertical and diurnal distributions. The record was taken from a fixed mooring in the North Basin over a 24-hour period, and shows individual fish targets ranging to 30 m throughout the day. A well defined 'scattering layer' makes regular migrations nearly to the surface at midnight. The layer appears particularly dense at depth within the 33° echo-sounder beam, but as it approaches the surface in the narrower part of the beam it can be seen to be composed of targets which are detected as individuals. The larger fish do not migrate to the surface at night.

System Comparisons

The H.A.D.A.S. and EK500 results quantify this process. A comparison between the peak target strengths within the scattering layer shows the H.A.D.A.S. (49 kHz) at -54 dB, the EK500 Split Beam (38 kHz) at -63 dB, and the EK500 Split Beam (120 kHz) at -70 dB (Figure 4). The Biosonics Dual Beam (420 kHz) peak was at -75 dB (Kubecka *et al.*, 1993).

Of these results, the -54 dB and -63 dB are reasonably compatible with fish between 4.0 cm and 2.0 cm respectively. The frequency of other targets within the distribution falls fairly steadily with increasing strength, and shows less variation between the systems.

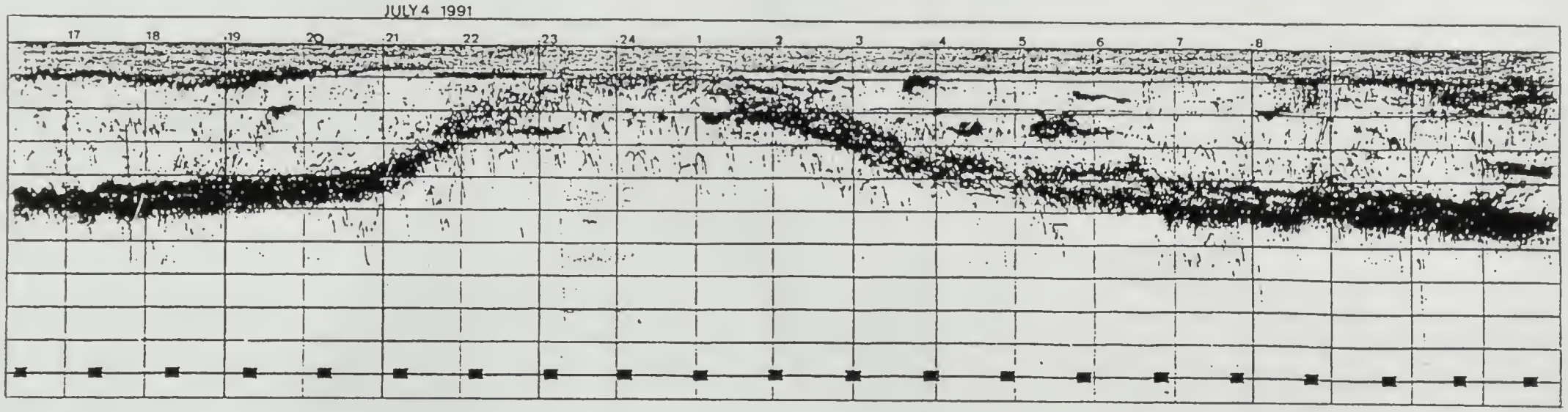
Overall target strength distributions are shown in Figures 5a and 5b. The strongest target detected was -30.75 dB at 38 kHz on the EK500, thus suggesting a fish length of approximately 75 cm. There is a secondary peak at approximately -40 dB to -45 dB (10-20 cm fish) on the H.A.D.A.S. and the EK500 (38 kHz).

Catch Data

A total of four hours of trawling in the scattering layer yielded 42 Charr of standard lengths between 4.0 cm and 27 cm, plus some Sticklebacks. The hauls are combined in Figure 6a and show a peak of around 10 cm, doubtless influenced by the selectivity of the sprat net. Figures 6b and 6c picture the fish of the pelagic. Gill-netting shows the maximum length of Charr to be approximately 30 cm, and the larger fish to be Trout, with the largest caught measuring 58 cm (Martin and

Figure 3

Night-time Migration of Pelagic Scattering Layer



Recorded on Lowrance X 16 echo-sounder (50 kHz).
Vertical lines at hourly intervals.

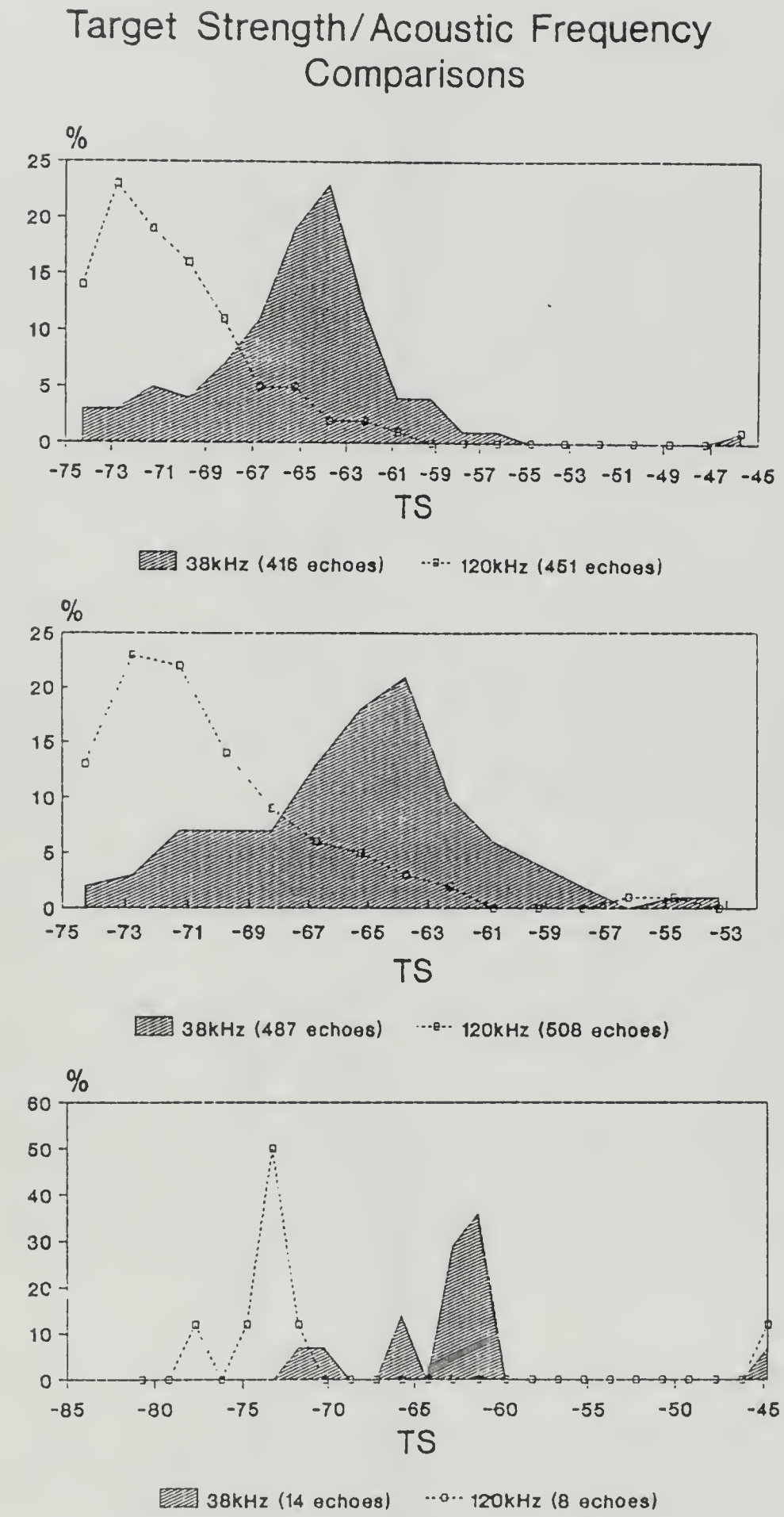


Figure 4

Taken from EK500 (split-beam) records, these traces compare the frequencies, 38 kHz and 120 kHz, measuring target strength simultaneously. The smaller scattering layer targets show a displacement, while the stronger fish targets are more similar.

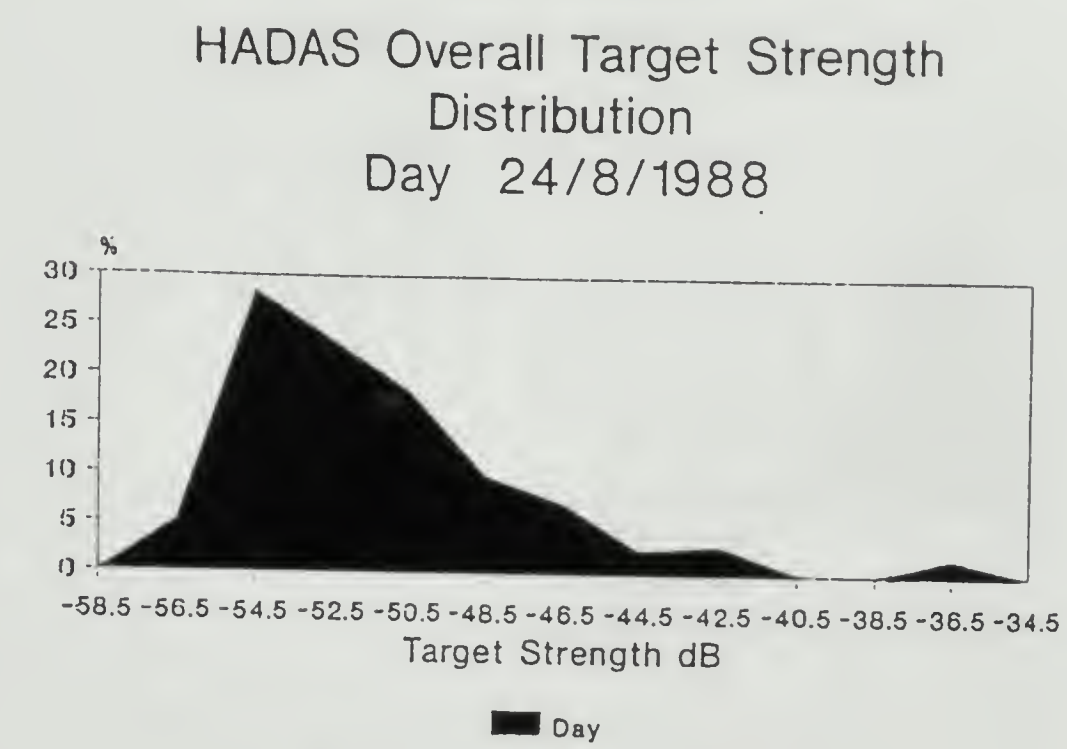


Figure 5a

The distribution shows the scattering layer strength, and a secondary peak at approximately -42 dB to -45 dB. This becomes more prominent at dusk as the smaller fish begin to evade detection as they move upwards.

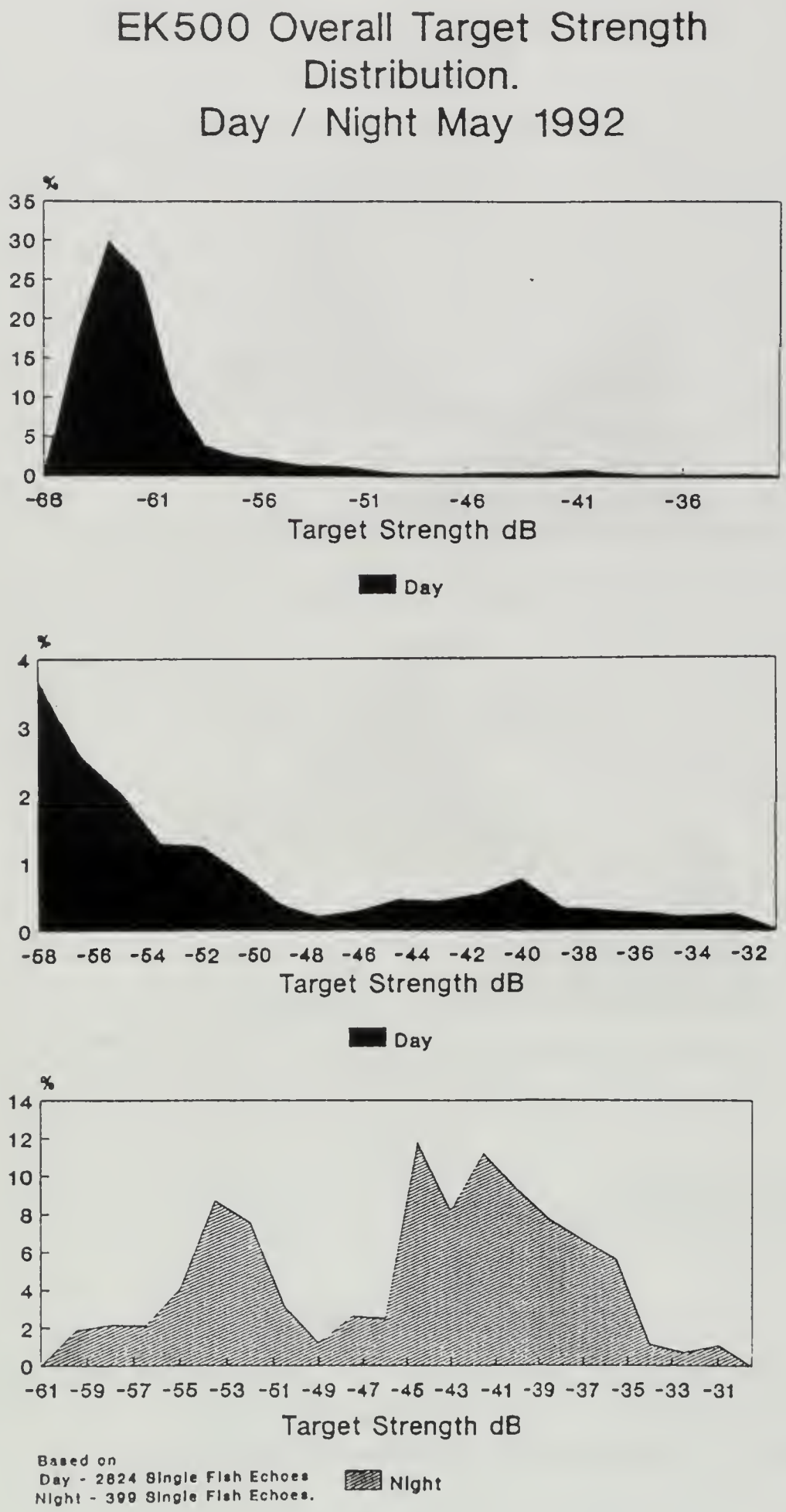
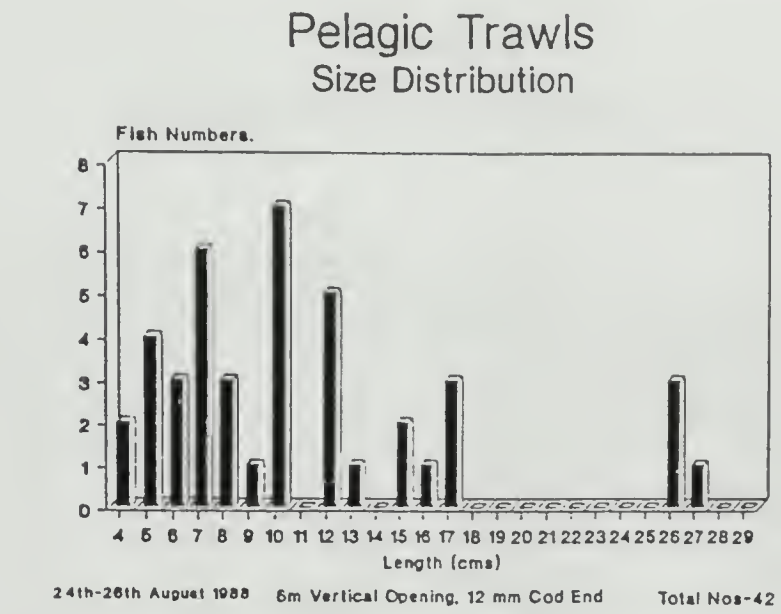


Figure 5b

The distribution is dominated by the scattering layer (-64 dB), but, when expanded, still shows the secondary peak noted for H.A.D.A.S. The night-time distribution is at midnight, when most smaller targets have risen beyond the detection limits.


Pelagic Trawls
Size Distribution
Fish Numbers.
0 1 2 3 4 5 6 7 8
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Length (cms)
24th-26th August 1988 6m Vertical Opening. 12 mm Cod End Total Nos-42

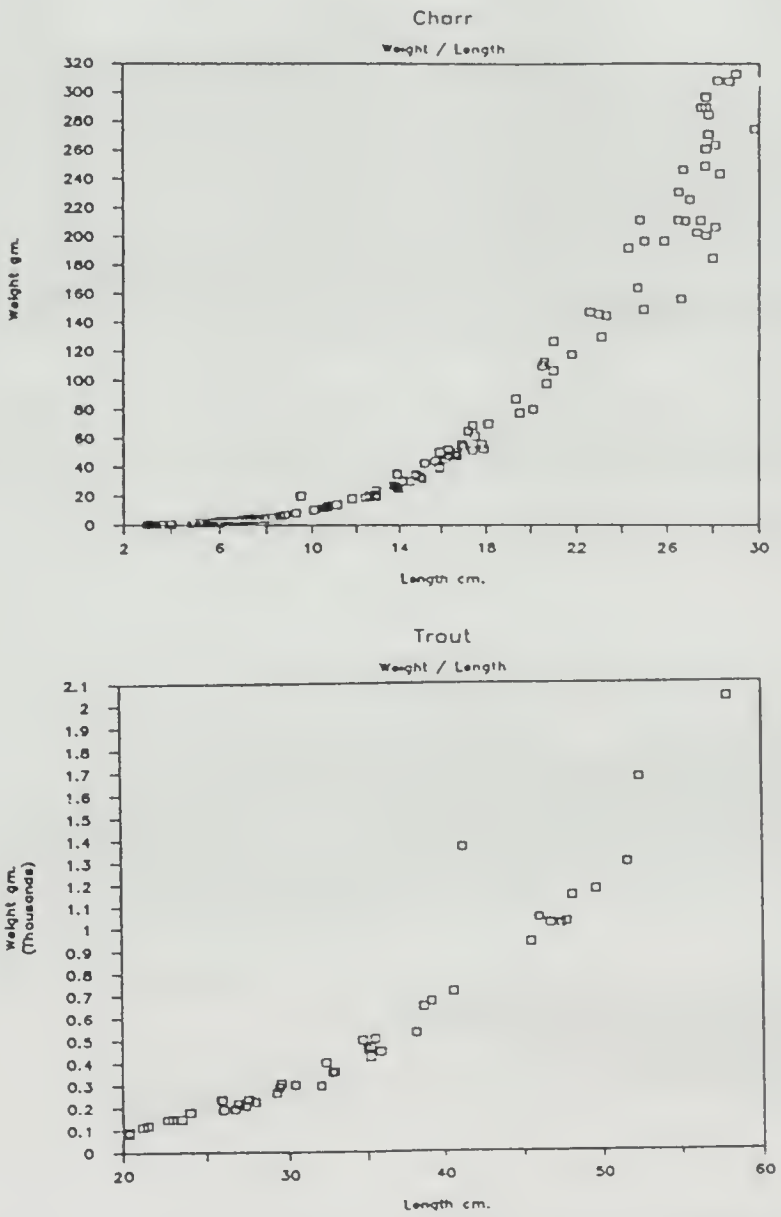
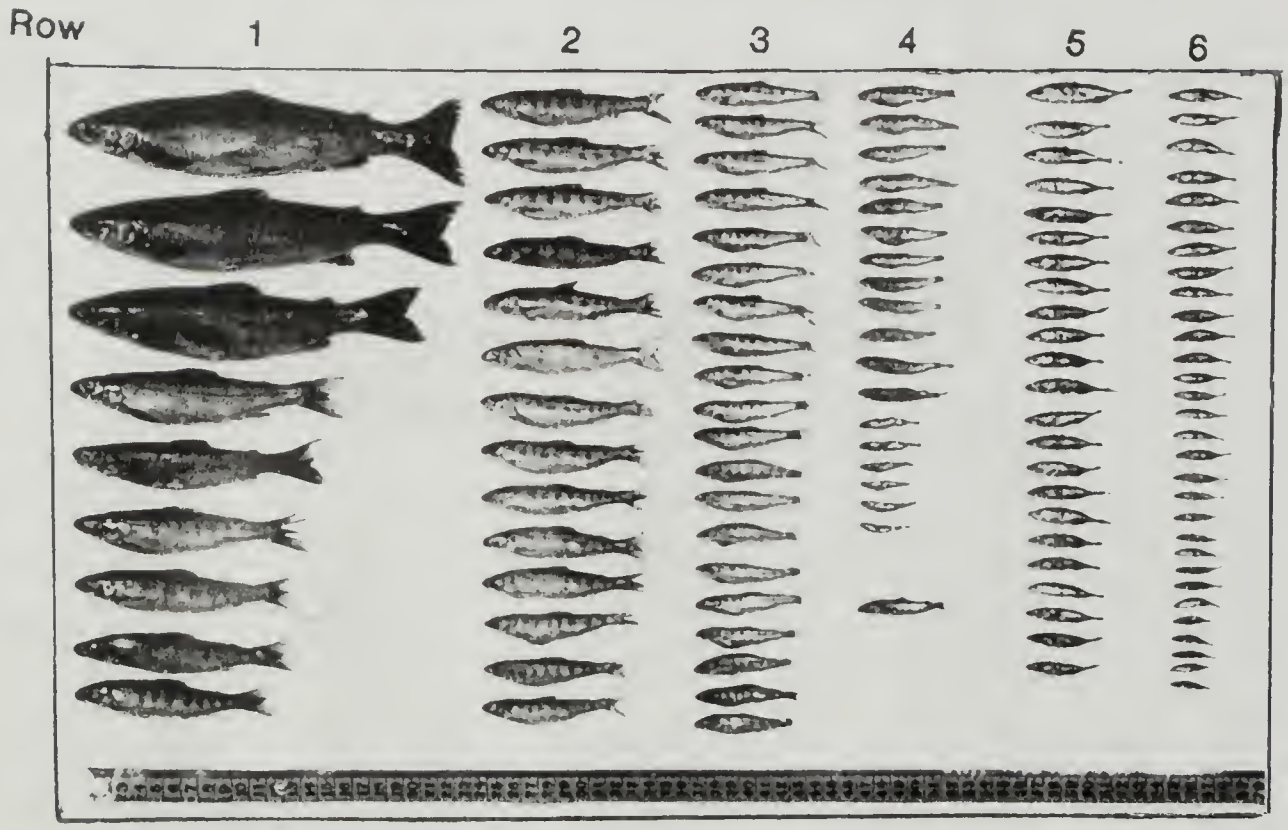


Figure 6a

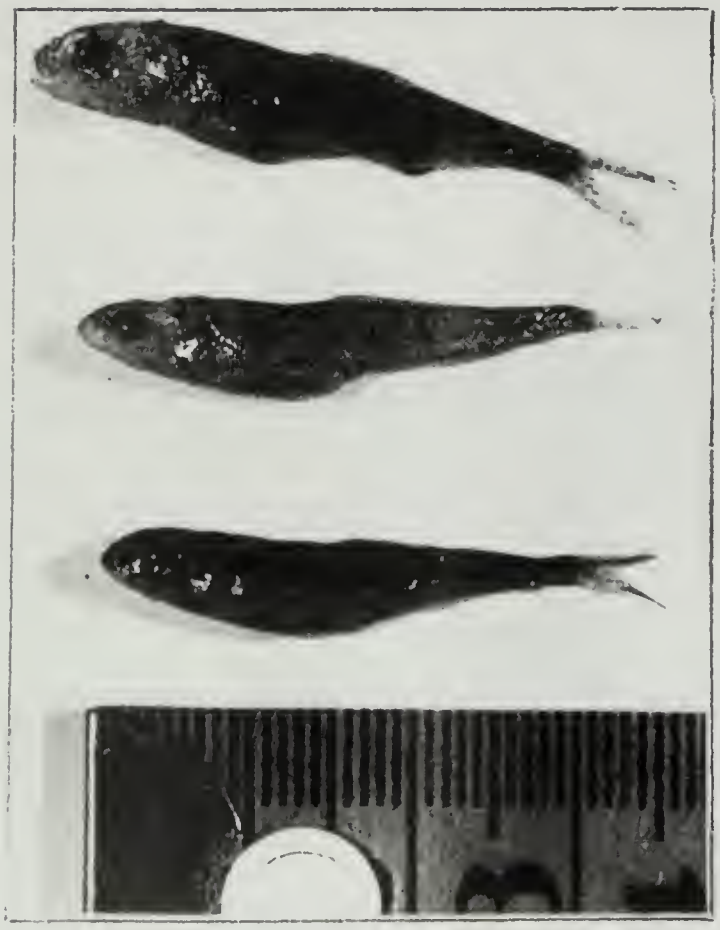
All trawl results are incorporated into the length/weight diagrams, which also include netting results from the fixed station.

Figure 6b

The Pelagic Fish of Loch Ness



Rows 1 - 4, 61 Charr between 3.0 and 23 cm in length; one juvenile Trout at bottom of row. Rows 5-6, 53 Sticklebacks.

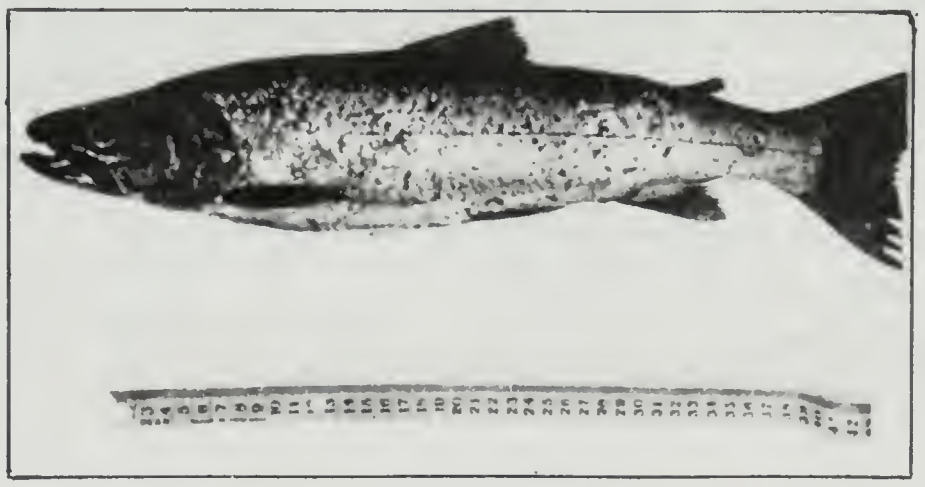


The smallest pelagic Charr. These include the 0+ age group and may contribute to the acoustic 'scattering layer'.

Figure 6c

The Pelagic Fish of Loch Ness

The pelagic Charr are zooplankton feeders, and grow to approximately 30 cm on a diet of *Bythotrephes, Daphnia* and Chironomid pupae. The majority are found to a depth of 30 metres.



Closer to the surface, Brown Trout feed on the same zooplankton species, but with a higher proportion of adult insects. When larger than 30 cm, however, they live deeper, preying upon the Charr.

This 1.0 kg specimen is 43 cm long, and the largest caught weighed 2.0 kg, with a length of 58 cm.

Shine, 1993). These larger fish could be expected to evade the trawl, while smaller ones could escape through the meshes.

Smaller fish were not taken until November 1992, when a very large trawl was undergoing trials from *Calanus*. Due to the closing of the codend meshes by stretching and further obstruction by leaves, 62 Charr down to 3.5 cm were retained, together with similar quantities of Sticklebacks. The 10 cm peak in the trawl samples would give target strengths of -48 dB (Lindem, 1984) or -45.7 dB (Love, 1977), which coincides quite well with the secondary peak in the target strength distribution noted above.

Fish Numbers and Depth Distributions

The H.A.D.A.S. runs were made in the South Basin in August 1988, and showed total numbers of nearly 1,500 fish/ha (Figure 7a). The mean of the May 1992 EK500 runs in the North Basin showed a total of 340 fish/ha (Figure 8a). Both these estimates include scattering layer targets. The remainder amount to no more than 20 fish/ha in the North Basin (EK500 38 kHz, Figure 8b) and approximately 400 fish/ha in the South Basin (H.A.D.A.S. 49 kHz (Figure 7b).

The depth distribution shows all target strength classes to be most numerous around the area of the scattering layer, but with substantial numbers of the larger fish above it.

Vertical Migration

The dusk 5.0 km run with the H.A.D.A.S., and the EK500 midnight runs (Figures 9a and 9b), clearly show the smaller targets migrating to the extent that they are almost absent (too shallow to be surveyed) in the EK500 records.

The larger fish migrate to a much lesser extent; indeed it would appear that the migration becomes progressively less with increasing size. It is interesting that, despite the drop in mean numbers from 341/ha to 31/ha at night, the EK500 SA figure (total integrated value) has barely changed, showing the very low 'acoustic weight' of the scattering layer targets (Figure 10).

North-South Density Gradient

The EK 500 length run, made in May 1992 from north to south along the axis of the loch, showed patchy numbers but a reasonably consistent target strength

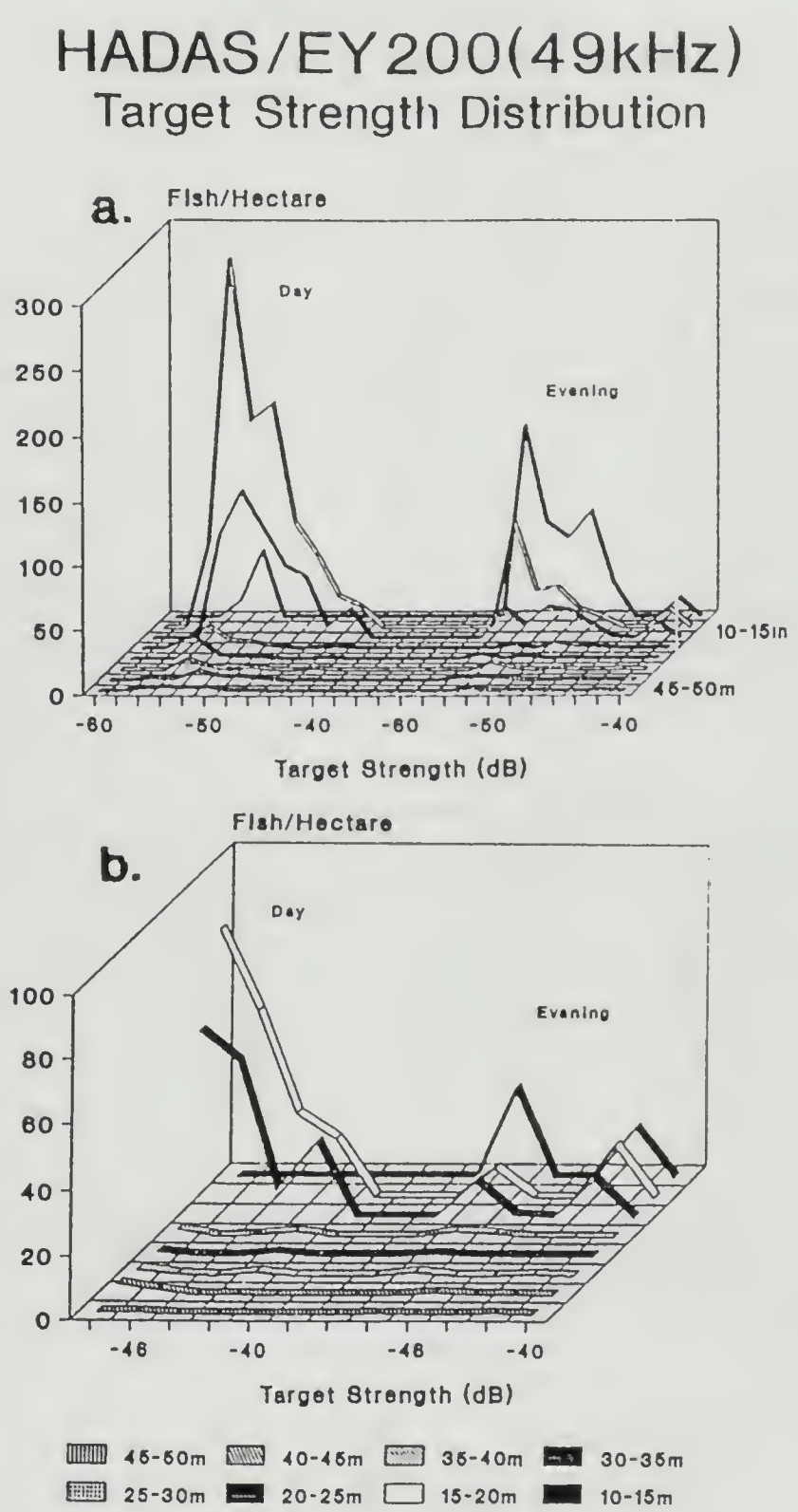


Figure 7

The distribution by depth shows the peaks moving up the depth layers at dusk. Also shown are the numbers per hectare, which amount to nearly 1500/ha in the South Basin. The lower diagram shows the larger fish remaining deeper by night.

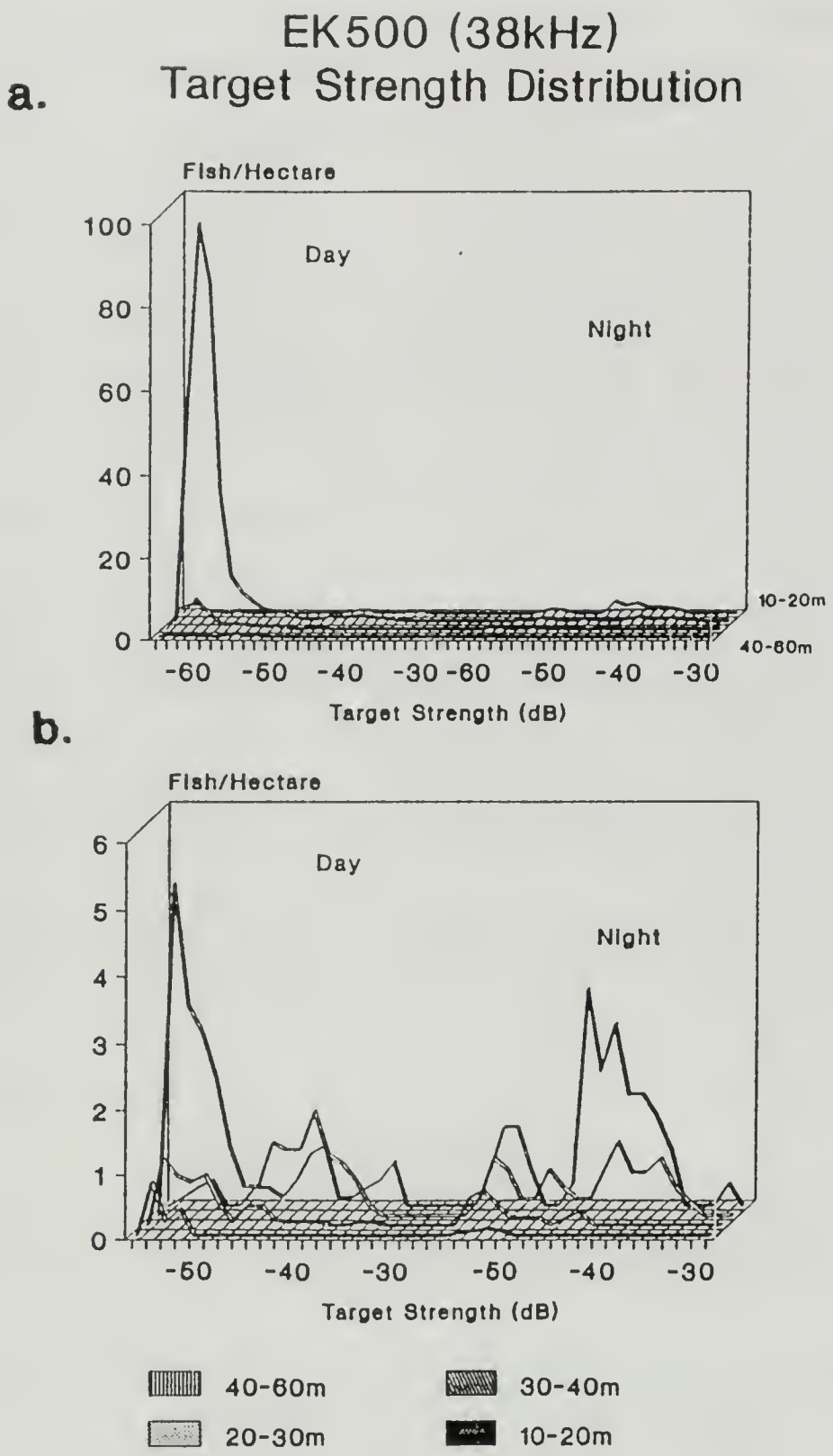


Figure 8

The North Basin has much fewer fish (340/ha) than the South. The expansion shows the -40 dB to -45 dB peak still detectable at 10-20 m at midnight. It is clear that the larger fish represent a very small percentage of the total numbers.

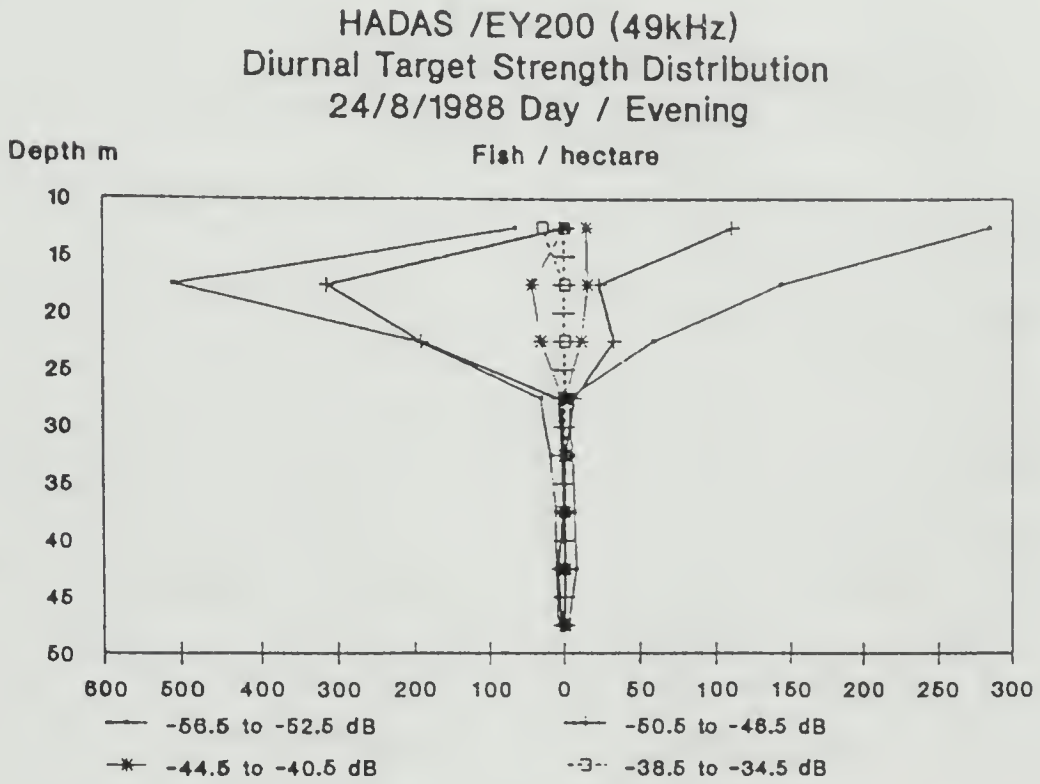


Figure 9a

These paired graphs for day and evening analyse the movements of individual size classes during vertical migration. Fish stronger than -40 dB remain at depth in substantial numbers.

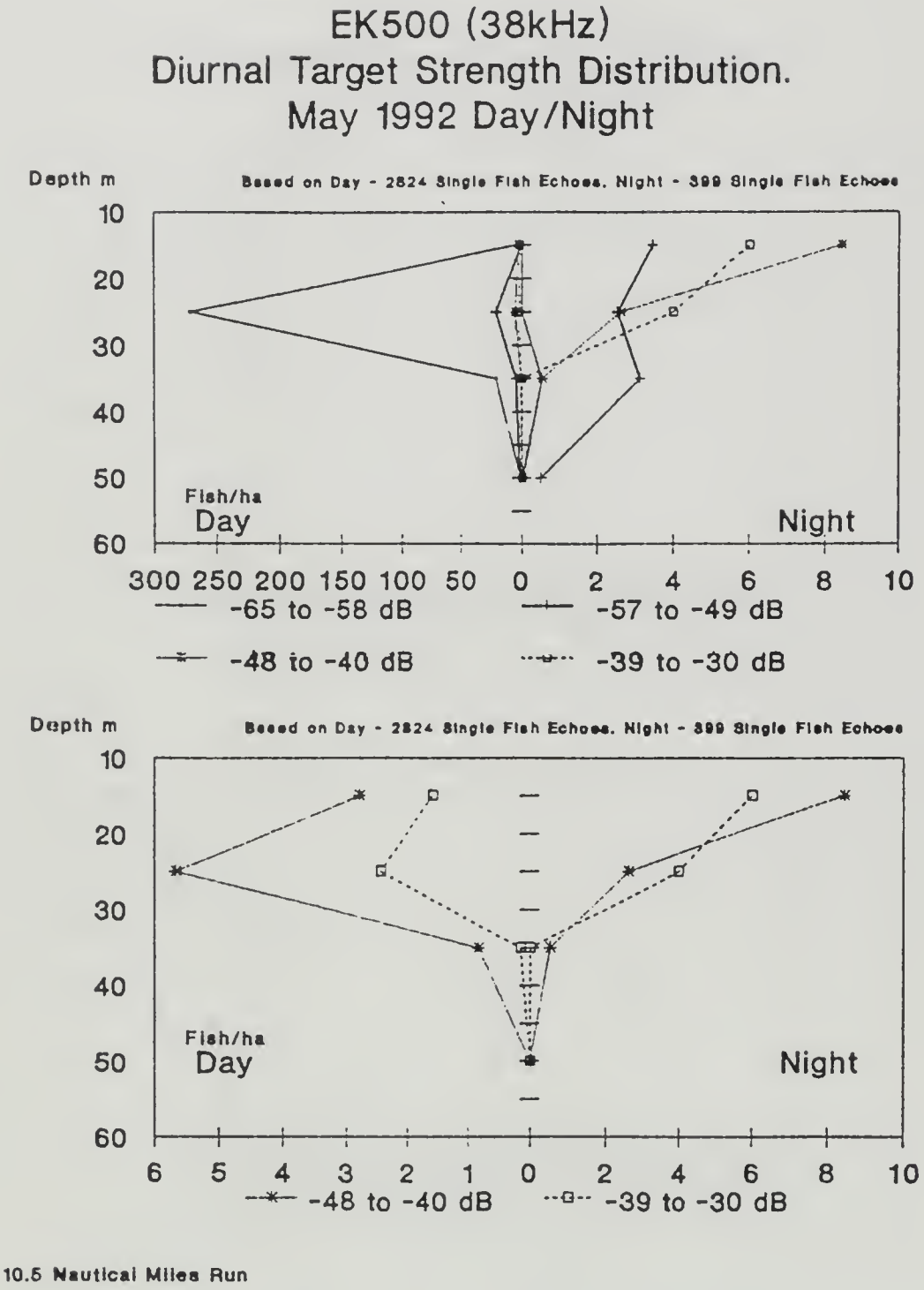


Figure 9b

The EK500 split beam shows similar migration patterns to the H.A.D.A.S. The smallest classes, however, (-65 dB to -58 dB) disappear upwards, while the largest (-39 dB to -30 dB) have not decreased in numbers.

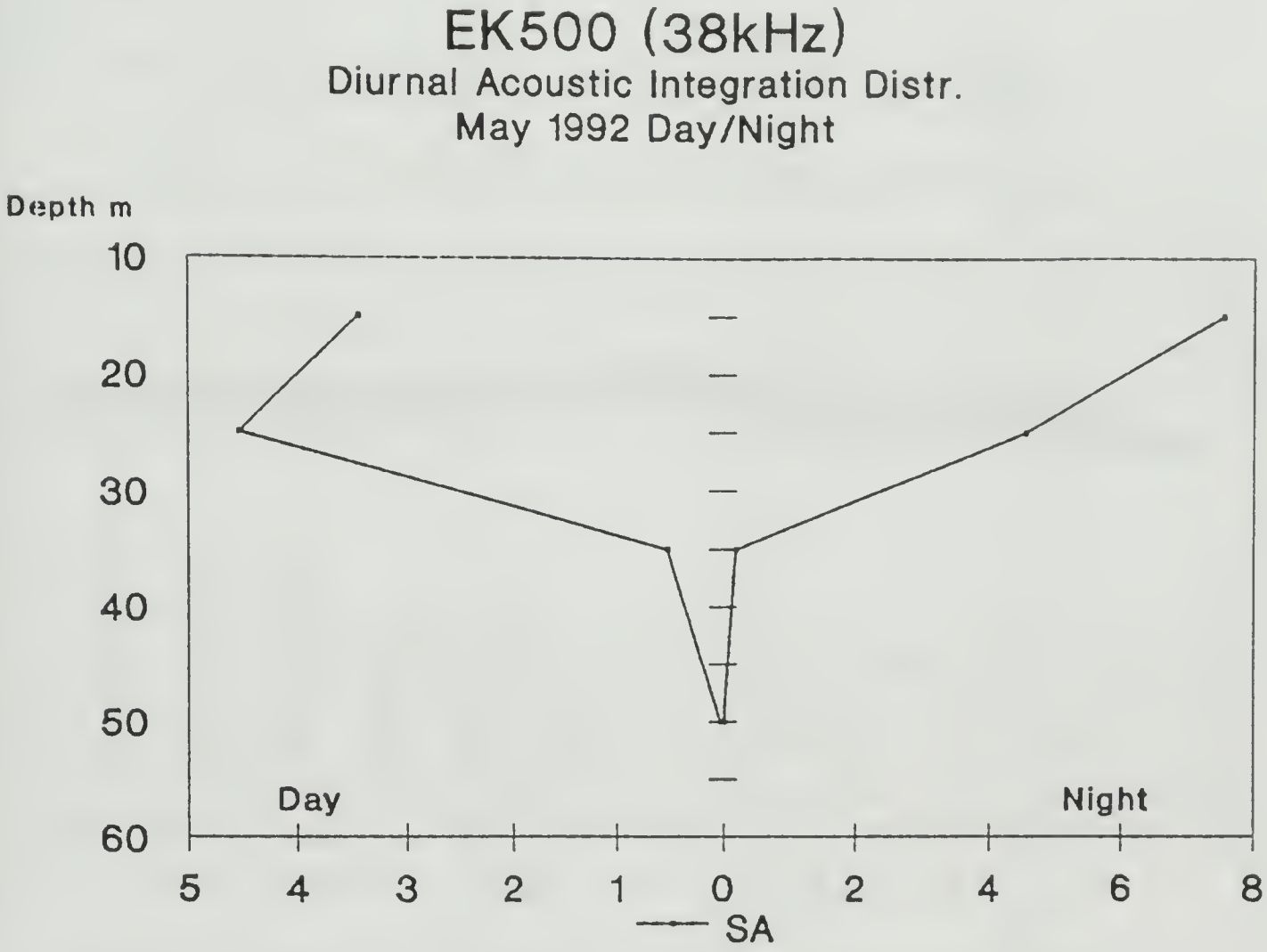


Figure 10

Despite the reduction in mean numbers at depth, from 341/ha to 31/ha at night, the acoustic integration (measure of biomass) remains similar. This shows the small biomass of the scattering layer.

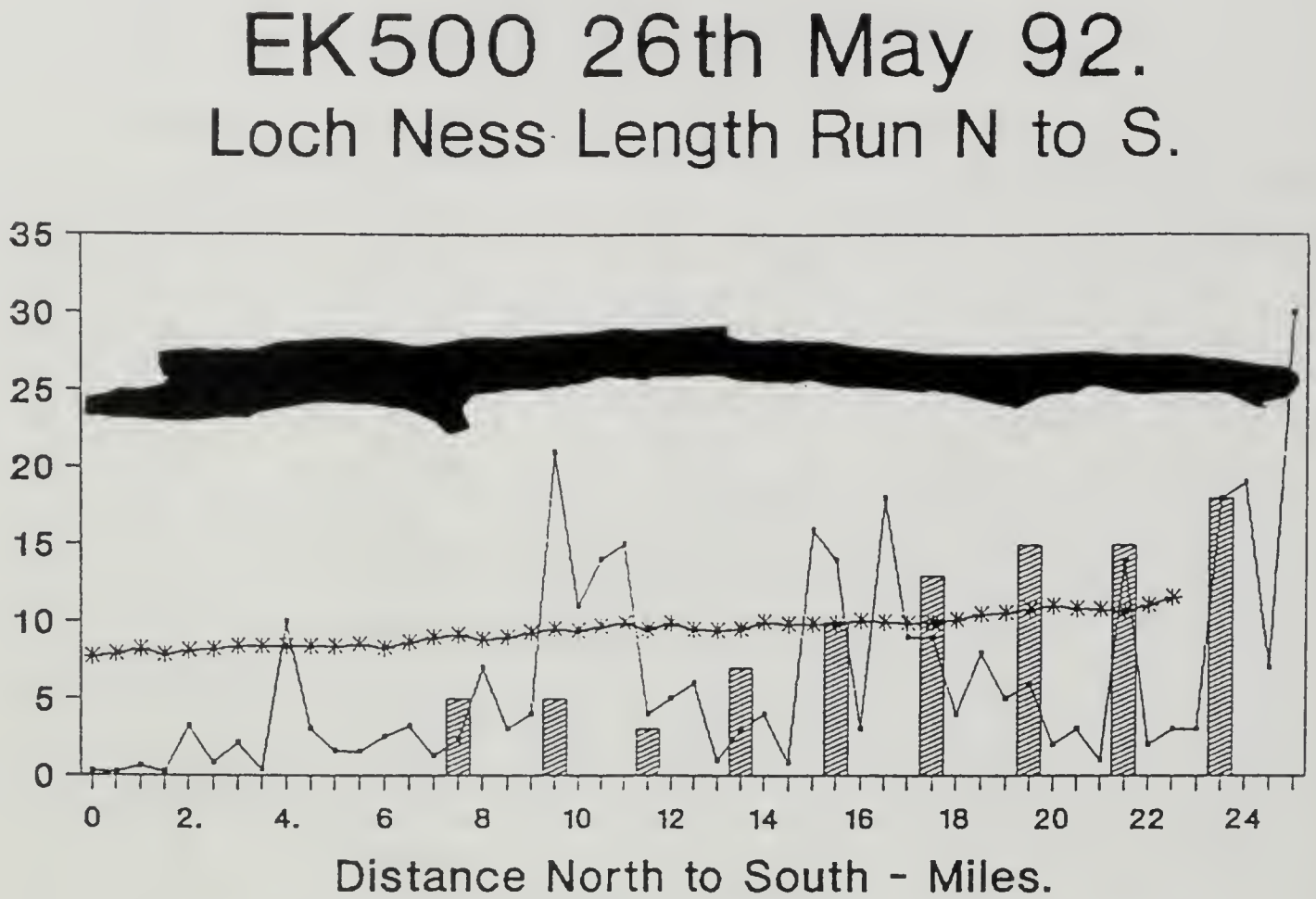


Figure 11

A length run along the axis of the loch, combining acoustic biomass, zooplankton density, and temperature. (The 'miles' are nominal, as measured by a ship's log). The distribution is patchy, but shows clear increases towards the south.

distribution. There was a clear increase in fish numbers from north to south (Figure 11. Plates 1 and 2). This confirms previous qualitative observations throughout the 1980s, particularly in October 1987 (Shine and Martin, 1988).

While this run was being made, a Clarke-Bumpus zooplankton sampler was towed at approximately 20 m, close to the scattering layer. Settled volumes of zooplankton also showed a definite increase towards the south. A mean of only 8.0 fish/ha was found above the scattering layer, as opposed to 419 fish/ha within it. However, a substantial portion of the biomass (mean SA 2.64) lies above the 20-40 m scattering layer depths (mean SA 6.39). This again emphasises the low biomass of the majority of individuals in the scattering layer.

Overall Estimates

The patchy distribution makes overall estimates speculative. The mean integration figure apportioned between the various size classes of the target strength distribution gives the numbers per hectare. A mean weight can be estimated through the length/weight charts (Figure 6a) by converting the target strength classes to lengths. The mean weight is then multiplied by the numbers given by the integration.

Based upon the target strength distribution, given by the 10.5 nautical mile runs and the mean of the length run integration figures, the mean numbers are 427 fish/ha and the biomass 3.1 kg/ha. Thus the resident pelagic fish stock would be 2,433,900 with a biomass of 17,670 kg. This estimate is exceeded by its statistical confidence limits, because of the patchiness of the numerical distribution.

Zooplankton

In Figures 12a to 12e plankton diurnal migration diagrams are presented, which show that from at least March onwards a pronounced vertical migration takes place involving the copepods *Diaptomus gracilis* and *Cyclops strenuus abyssorum*. These are the dominant species. The Cladocera are present in much fewer numbers, and *Bosmina coregoni* in particular appears at the greater depths (Figure 12b). *Daphnia hyalina* appears to migrate to some extent while *Bosmina* does not. The larger predators, such as *Leptodora kindti*, *Bythotrephes longimanus* and *Polyphemus pediculus*, have not been caught in sufficient numbers to be sure of their movements, although underwater camera work in 1992 showed diurnal migration in *Leptodora*. In Lakė Huron (Canada), however, *Bythotrephes* has

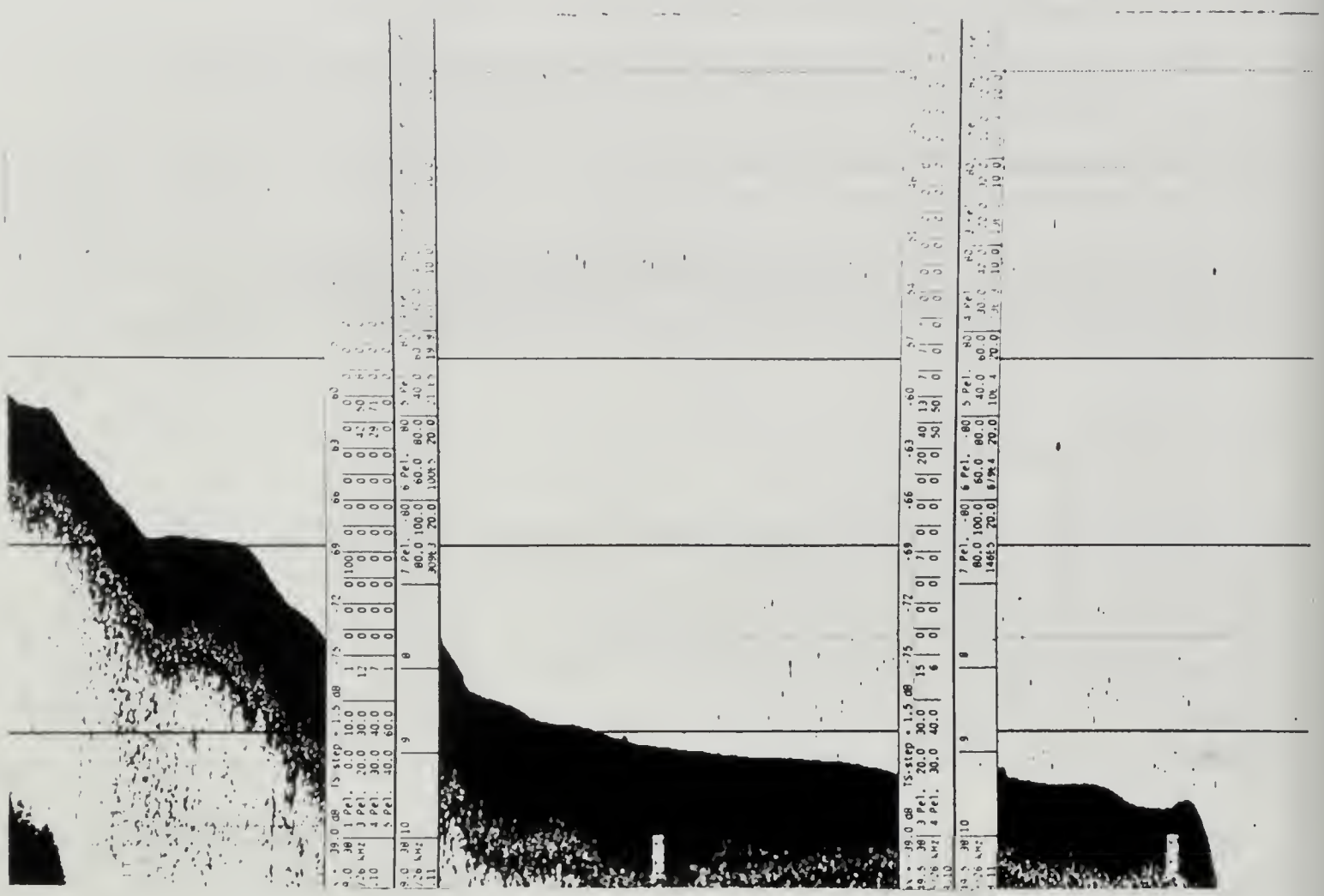


Plate 1

Simrad EK 500 chart traces taken during a length run in May 1992. They clearly show the small numbers of fish at the north end (Plate 1) and the greatly increased numbers at the south (Plate 2).

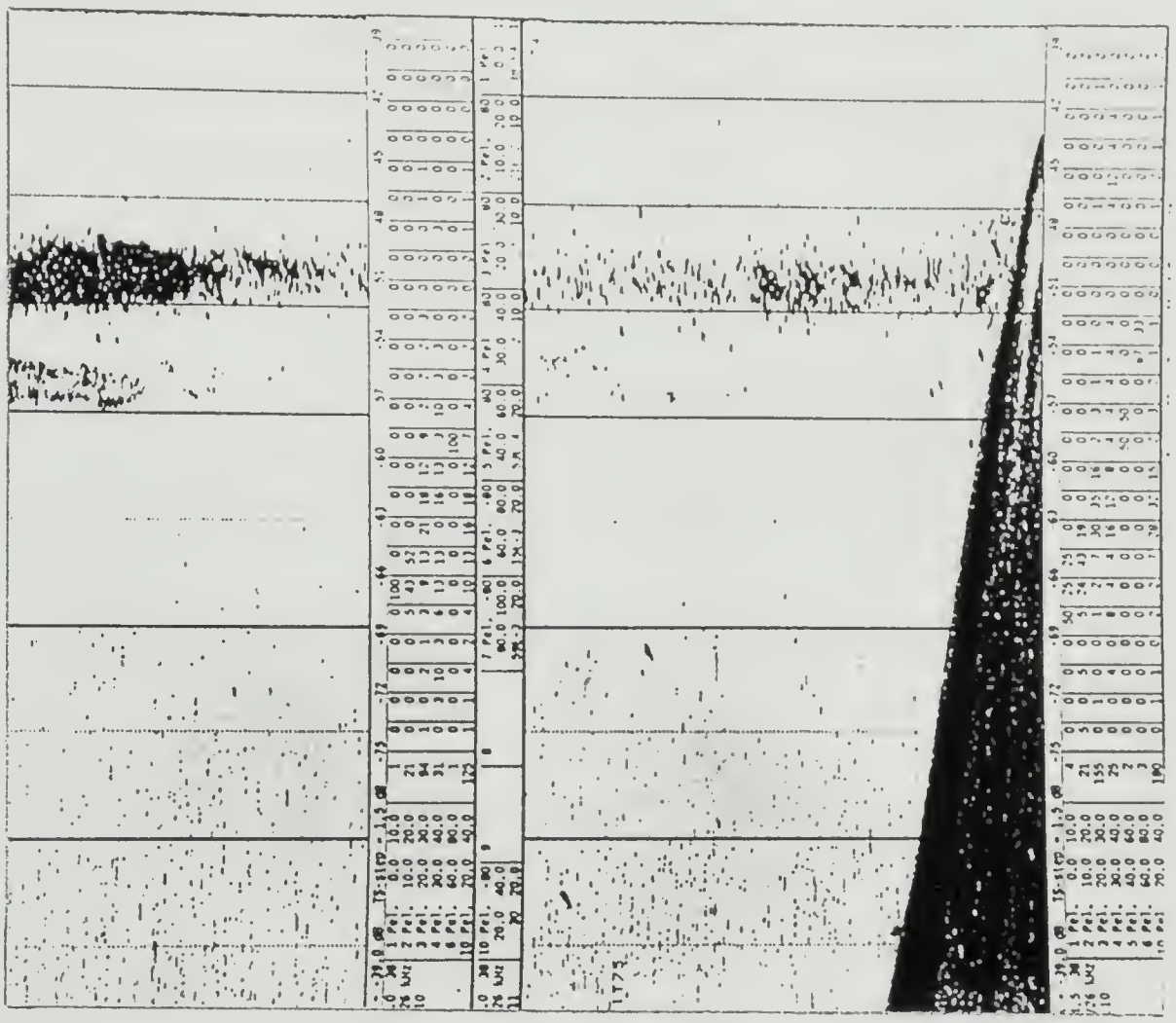


Plate 2

Simrad EK 500 chart traces taken during a length run in May 1992. They clearly show the small numbers of fish at the north end (Plate 1) and the greatly increased numbers at the south (Plate 2).

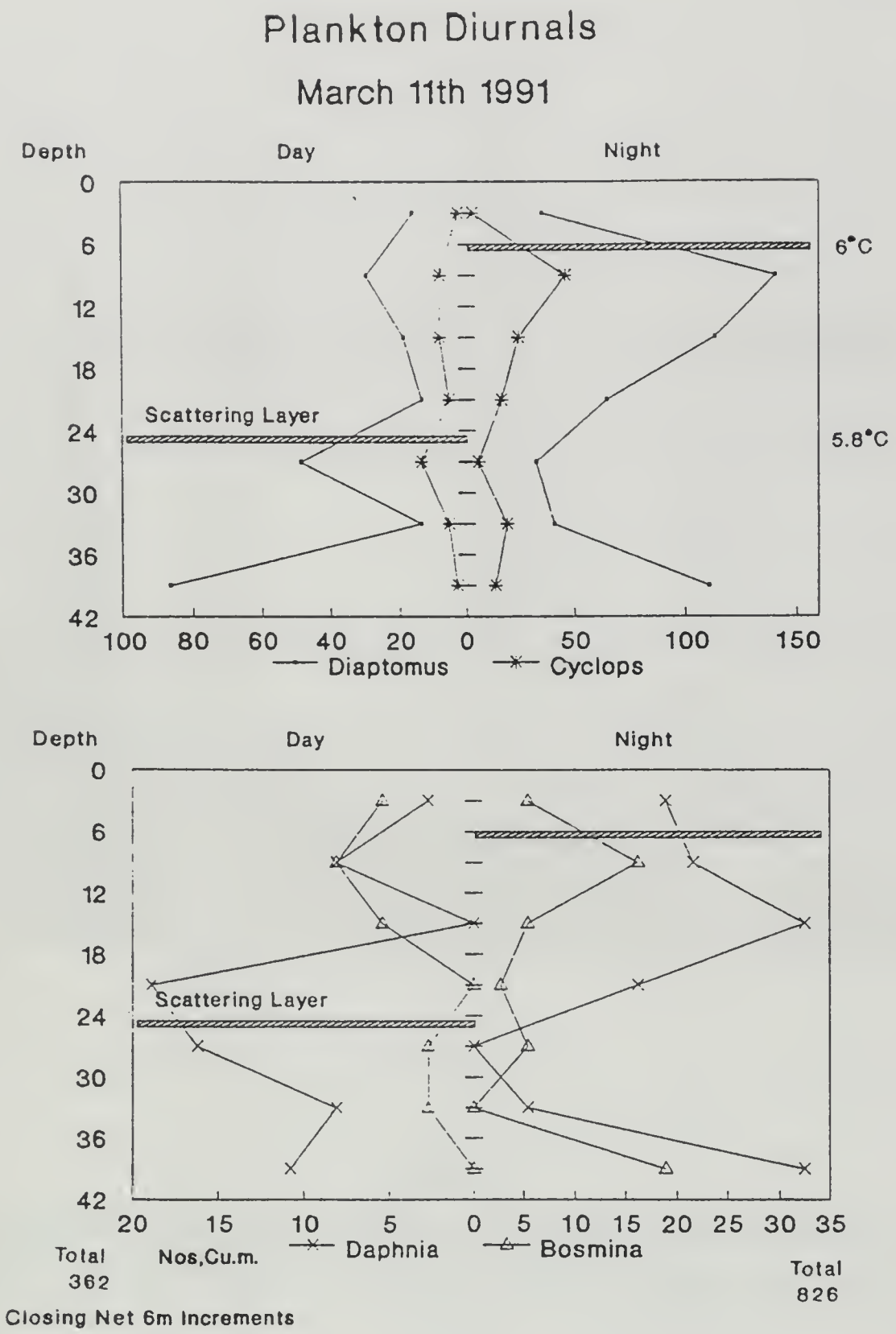


Figure 12a

This and the following figures show the increase in total plankton numbers towards autumn, and the vertical migration of individual species in relation to thermocline and scattering layer positions. In this example the copepods migrate more than the Cladocera, and the scattering layer rises from water at 5.8° C to 6.0° C at the surface.

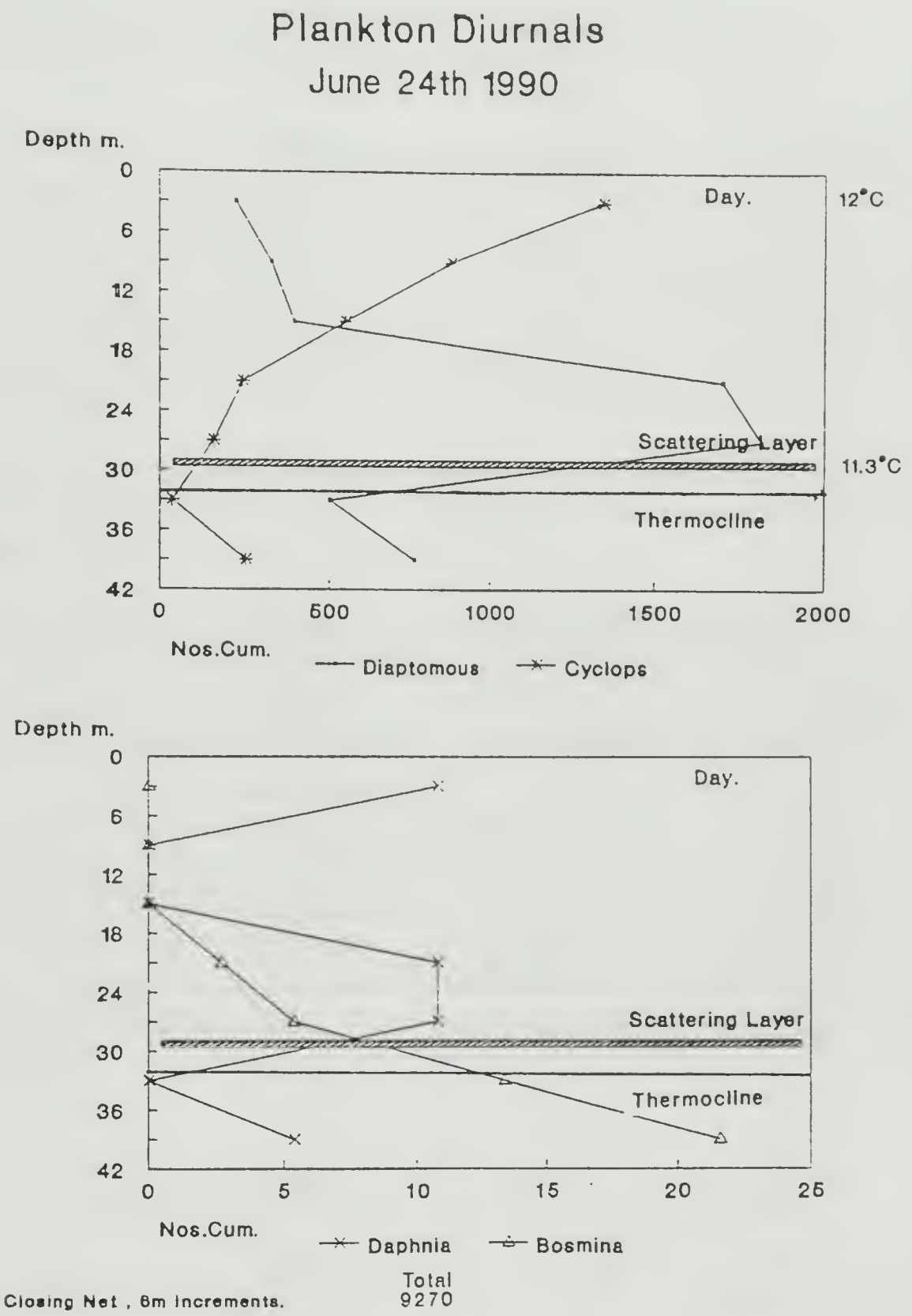


Figure 12b

This daytime distribution emphasizes the numbers of *Bosmina* at depth beneath the thermocline, and also the unusual concentration of *Cyclops* at the surface.

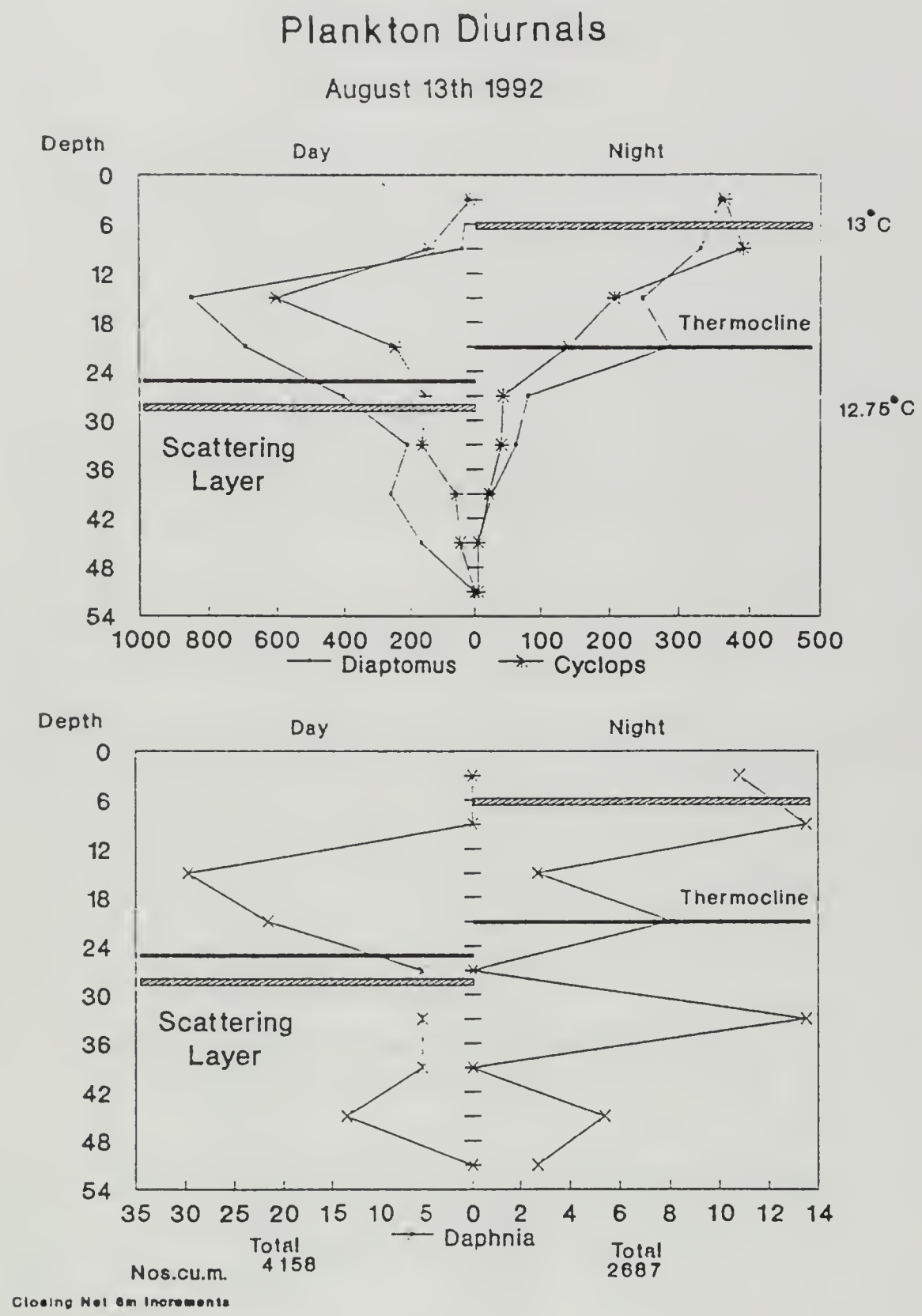


Figure 12c

The classic migration of the copepods is shown here, together with the frequent observation that the daytime scattering layer can be found beneath the zooplankton maximum.

been reported by Vanderploeg, Liebig and Omair (1993) to lie in a narrow diurnally-migrating horizontal band and to favour Cladocera as prey.

In Loch Ness, *Cyclops* has occasionally been observed to be concentrated at the surface by day, the reverse of the usual pattern (Figure 12b). Total numbers are seen to increase as the summer advances. Large variations also occur through horizontal transport, particularly due to internal seiche movements, for example in October 1985. Larger numbers have been associated with denser scattering layers (Marjoram, 1993). Levy, Johnson and Hume (1991) also report changes in fish distribution due to internal seiche.

By day, total zooplankton numbers are usually greatest just above the scattering layer, but sometimes coincide with it. Migration of the copepod element of the zooplankton is very similar to that of the scattering layer.

During the length run (Figure 11), zooplankton numbers increased from north to south. All species were more numerous in the south, although there were differences in percentage composition. Cyclops increased from 26% to 64% while *Diaptomus* decreased from 45% to 28%. *Bosmina* decreased from 8% to 2%.

South Basin tows with the optical plankton counter within deep acoustic scattering layers (Figure 13a) do show increases of particle numbers, mostly approximately 0.25 mm, within the layers. However, the greatest peaks in particle densities can be from depths where there are no acoustic layers at all. The plankton net attached to the optical counter yielded the results shown in Figure 13b. The most notable feature is the great preponderance of *Bosmina* at these greater depths.

Scattering Layer Movements

The nightly rise appears to be light triggered, commencing as the light falls to approx 1.0 μm/s at 10 m depth (Marjoram, 1993). The dawn sinking occurs as the light reaches the same level. It has already been observed that the layer does not necessarily establish in the thermocline by day, but very often does (Shine and Martin, 1988). In the summer of 1992 the mixed layer was 12°C or more, and the scattering layer did establish in the thermocline at a lower temperature. Experiments with an inverted transducer showed that the layer does not necessarily rise to the surface at night but remains at approximately 5.0 m until dawn (Marjoram, 1993).

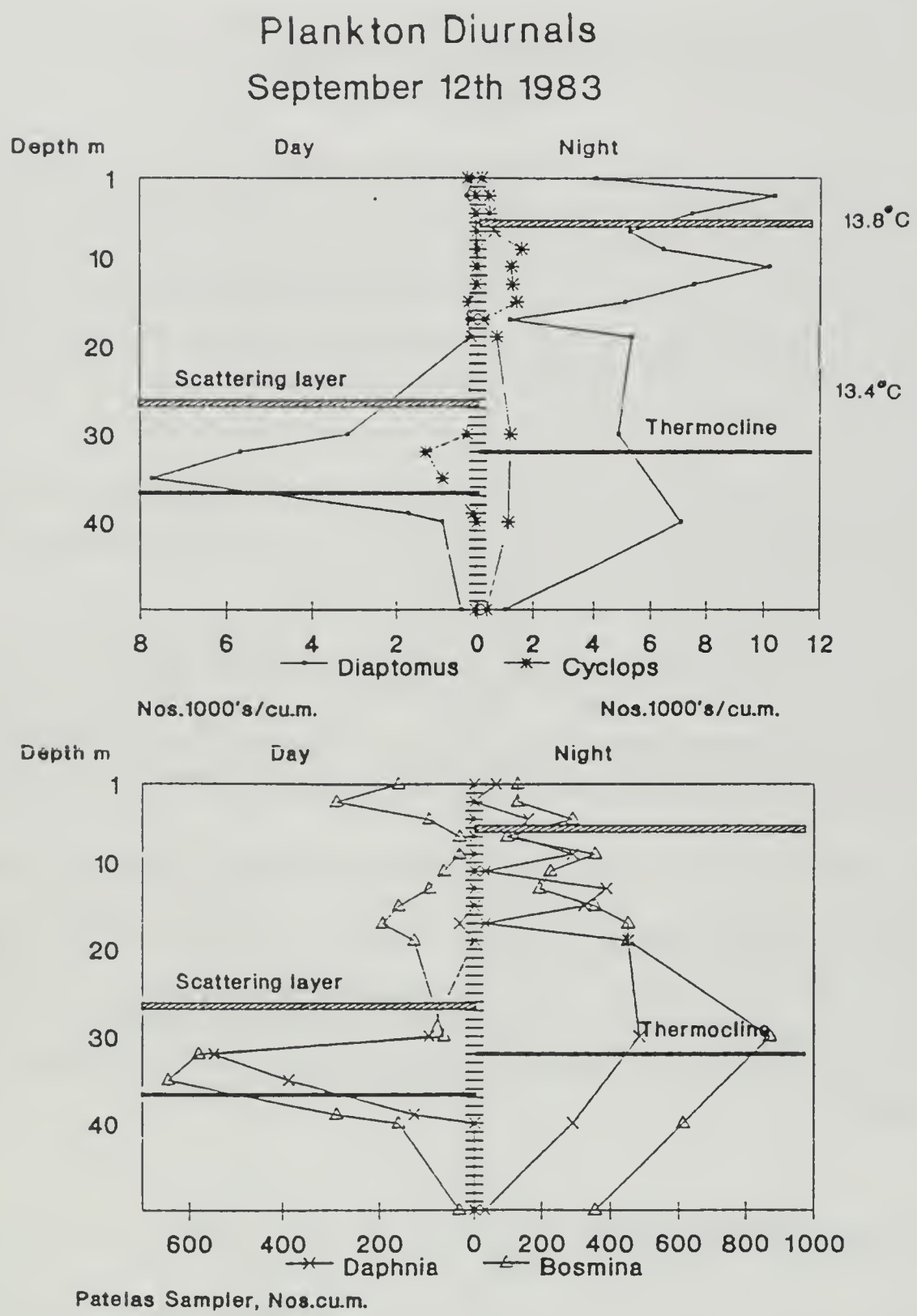


Figure 12d

Again the copepods exhibit vertical migration, while substantial amounts of *Daphnia* remain at all depths.

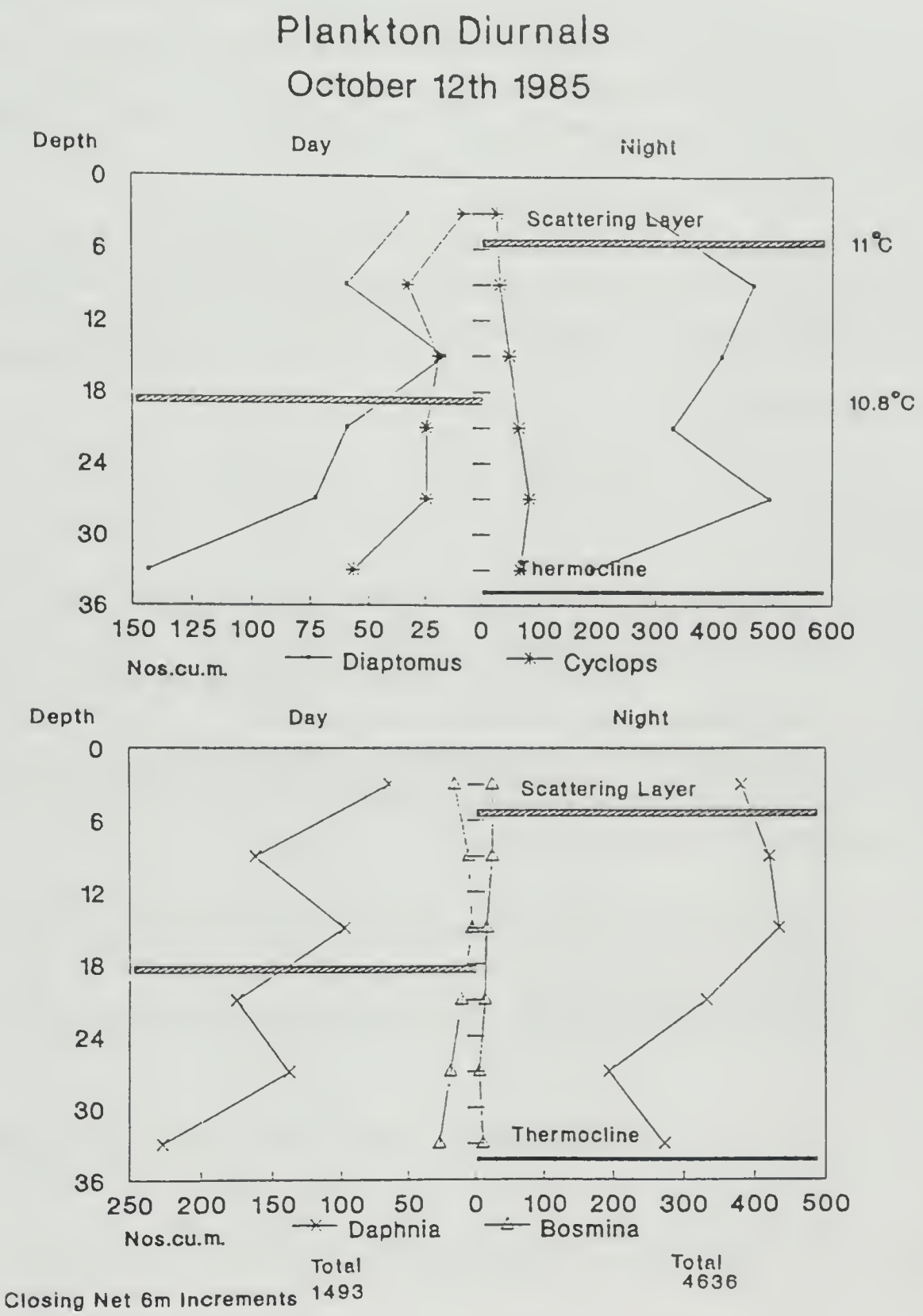


Figure 12e

The influence of an internal seiche appears to damp the zooplankton migration, but not that of the scattering layer.

In the southern fixed station experiments of 1984 (Shine and Martin, 1988), the scattering layer was seldom entirely absent, even during north-east flowing internal seiches. In the North Basin, however, it is notable that the scattering layer is strongest during north-east winds and may disappear entirely during south westerlies.

Frequently there is an across-loch tilt in the scattering layer. Figure 14 shows tilting during a period of south-west winds, with the layer deeper on the southern shore. Another feature is the presence of 'ramps' in the scatterers, sloping down towards the wind direction. They are approximately 440 m long and slope at an angle of approximately 4°.

Discussion

The difference in target strength of the smaller scattering layer targets recorded by the various systems is of some interest. To begin with, it would seem that the various peaks are not the result of optimum detection thresholds, since total numbers are very similar. In an example on the EK500, 1,600 targets/ha were recorded at 120 kHz and 2,120 targets/ha at 38 kHz simultaneously, whereas the target strength peaks were at -70 dB and -62d B respectively (Mr. Erik Stenerson, pers. comm.).

Differences could result from calibration or time-varied gain (T.V.G.), but results have been comparable on three separate occasions. It may be that resonance effects are responsible. There has been little acoustic work on very small fish.

Burczynski, Michaleitz and Marrone (1987), in a survey of Rainbow Smelt *Osmerus mordax,* found that Love's (1977) formula appeared to underestimate the length of 5.6 cm fish by approximately 2.0 cm. Another point is that very few of the fish surveyed will be on the beam axis and so be in true dorsal aspect.

This will reduce signals even though the beam pattern may have been compensated. Mr. R. Johnson of Biosonics (pers. comm.) suggests that the reduction will be greatest at the higher frequencies, which is consistent with the pattern of our observations. The low target strengths, especially at the higher frequencies, have introduced the suggestion that the individuals of the scattering layer are too small to be fish. Other candidates are chironomid larvae and pupae, larger zooplankton such as *Leptodora* or perhaps some unrecorded crustacae.

Shine and Martin (1988) reported 4th instar chironomid larvae, particularly *Sergentia* sp., taken in the pelagic during plankton hauls. Larvae have also been observed in quantity in the stomachs of pelagic Charr (Martin and Shine, 1993). Chironomid pupae have been collected by tow-nets within the scattering layer, particularly in May. It has been observed that, when placed in containers, the pupae do not necessarily emerge for two or three days. Therefore it seems possible that they may adopt a planktonic migration strategy while preparing for final emergence. Hauls taken later in the year, however, do not always yield significant numbers of chironomids even though the scattering layer is strengthening.

Experiments have been conducted by introducing quantities of 4th instar chironomid larvae and pupae into an echo-sounder beam (Lowrance Mach II, 50 kHz) at ranges up to 18 m. Only occasional traces were obtained, thus suggesting that detection was dependent on targets close to the beam axis, perhaps in multiples. Nevertheless, detection can be achieved and chironomids must be regarded as an important component of the pelagic community. Work should be undertaken to establish the target strength of chironomids.

Leptodora may be dismissed as a candidate, since it is not present in winter. In March 1991, for example, during a plankton diurnal, a scattering layer was observed in the absence of *Leptodora* (Figure 12a). The optical plankton counter showed the greatest concentration of smaller particles in zones not producing acoustic reflections. Therefore zooplankton are unlikely candidates.

With regard to other species, not hitherto recorded from Loch Ness, it should be born in mind that no plankton net, nor any other sampler, in ten years of work has ever shown traces of any such organism; nor has any been found in the sediments. No pelagic Trout or Charr examined (Martin and Shine, 1993) had consumed anything unusual.

The trawling of 3.5 cm Charr in the pelagic during November 1992 suggests a very low growth rate. In Martin and Shine (1993) it is shown that the 1+ Charr are between 4.0 cm and 7.0 cm long. The new material includes 0+ fish smaller than this (Mr. R.B. Greer, pers. comm.)

We have observed spawning Charr in December, which emphasises how small 0+ fish could be in the earlier summer months. No significant genetic differences have been observed between Loch Ness pelagic and benthic Charr (Dr. Sheila Hartley, pers. comm.) and a fecundity study by Meacham (1993) shows consistent

egg size increase from summer to December. It seems unlikely, therefore, that there is a separate spawning population giving rise to such small fish in the autumn.

A further point is that in the earlier months, as in March 1991, the scattering layer is only detectable on more powerful echo-sounders. This suggests an increase in individual target strength (i.e. growth) as the year proceeds.

The scattering layer diurnal migration is similar to that of the copepods, but these do not occur significantly in the fish diet, which is similar for Charr between 4.0 cm and 30 cm. *Bythotrephes* and *Daphnia* are the main prey items, followed by *Leptodora*. Only the smallest Charr and some of the Sticklebacks contained some copepods. It was found by Fryer (1957) that *Cyclops strenuus abyssorum* is predatory upon *Diaptomus gracilis*. Loch Ness *Cyclops* have also been observed to feed on animal material, including *Diaptomus* (Mr. K.W. Heath, pers. comm.). A limited amount of plant material is also consumed, and perhaps this is why *Cyclops* maxima may sometimes be observed near the surface by day. *Diaptomus* shows the greatest diurnal migration, and this could be a response to predation by *Cyclops* and other zooplankton rather than by fish. In any case, the scattering layer generally lies below the copepod maxima. It seems reasonable, by contrast, to suppose that the much smaller numbers of *Daphnia* are a reflection of fish predation observed by Martin and Shine (1993).

At the same time, the smaller range of *Daphnia* migration may account for the decrease in the migration tendencies of the larger Charr. The migration of the scattering layer, if composed of fish, is perhaps a little surprising if one of the main food sources is *Daphnia*, which does not migrate to the same extent.

It could, however, be an energetic strategy similar to that exhibited by the Sculpin *Cottus extensus*, a larval fish of North America, which is a benthic feeder during the day and rises into the warmer surface waters at night. This speeds digestion and so growth rate (Wayne and Neverman, 1988). The scattering layer migration could be a predation response, but none of the pelagic Charr had consumed fish, and only a few of the smallest Trout take Charr of <6.0 cm.

The autumn *Daphnia* peak noted by Maitland (1981) and ourselves (Figures 12d and 12e) could perhaps be explained as the larger Charr move inshore to spawn, thus reducing the predation pressure. Other factors could be that the very large water mass of Loch Ness retains its heat longer than smaller lakes. Also there is generally an injection of allochthonous material (potential food) during equinoctial storms which bring the rivers into spate.

The *Bosmina* do not seem to migrate at all, and are consumed by many of the Charr, although seldom in significant numbers. The considerable numbers of *Bosmina* observed from the thermocline downwards suggests that they are filter feeding a detrital or microbial food source. In this connection, the persistent north/south gradient in fish, and often in zooplankton, is interesting. This presents something of a paradox, since George and Jones (1987) had found that both conductivity and chlorophyll-*a* maxima lie consistently in the North Basin. They suggested that this was caused by the slightly richer northern catchments. An explanation could be that allochthonous organic material brought in by rivers of the much larger, and wetter, southern catchments is much more important than the primary productivity.

If this material is processed through the microbial element, it could find its way to the zooplankton, particularly the filter feeding Cladocera, and so to the fish.

In this respect, the results of the length run along the axis of the loch are somewhat surprising, in that the cladoceran *Bosmina* decreases in percentage towards the south. This species is the one most likely to be utilising allochthonous inputs, and so might be expected to form a greater percentage of the plankton composition in the south. However, it should be borne in mind that the samples were from a depth of 20 m, and that some thermocline tilt might have been present due to a light north-east wind. This could have affected the observed distributions. Numerically all species increased in the South Basin.

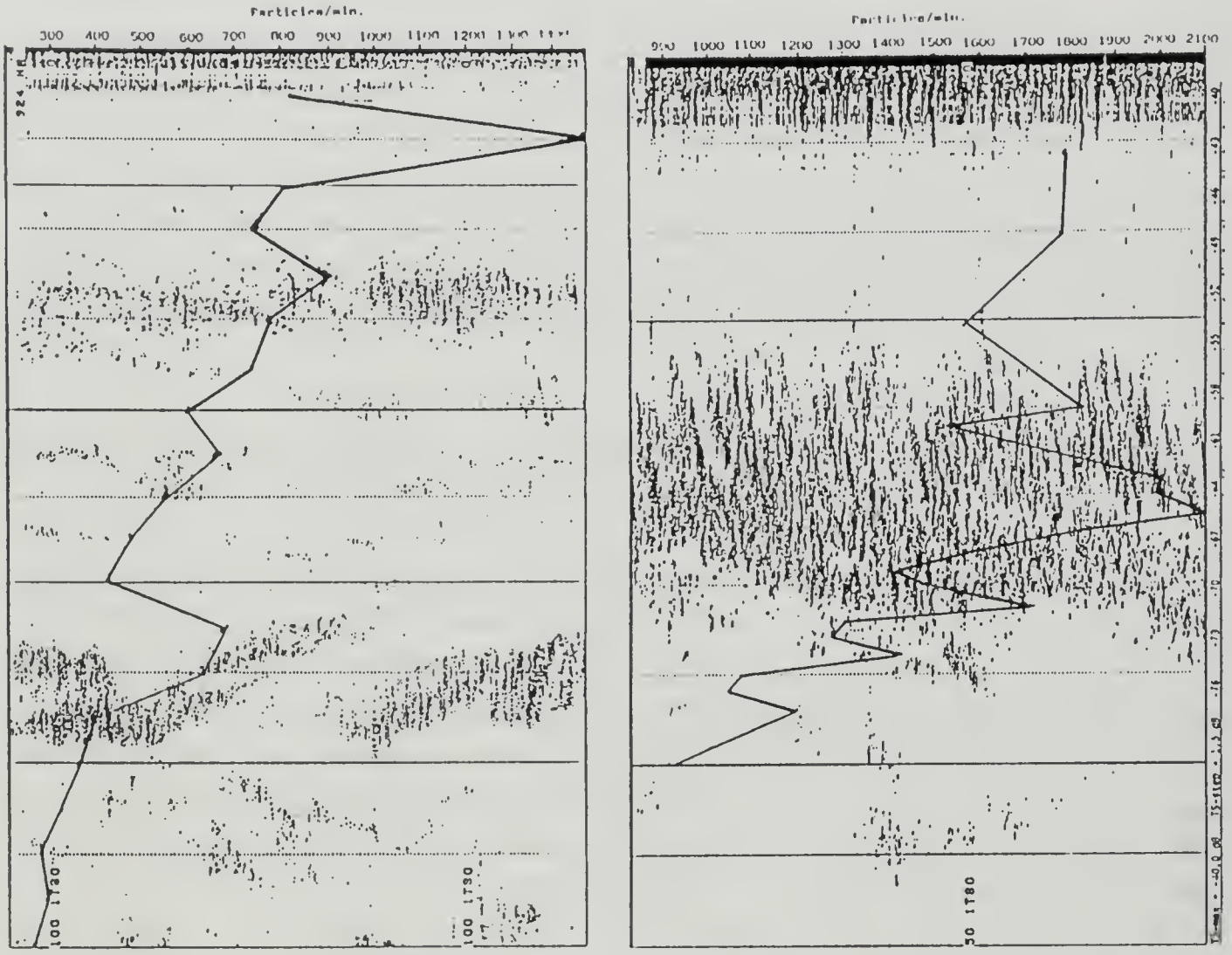
The increase in fish numbers towards the south is particularly pronounced in the smaller targets of the scattering layer. During the 'steady state' produced by the normal south-west winds, these scatterers would spend the majority of their time close to the thermocline and therefore in the south-west return current produced. By contrast, a number of length runs have shown that zooplankton numbers at the near surface increase down wind (unpublished data).

The deeper scatterers would only rise into the north-east surface drift for the six hours of the short northern nights. Shine and Martin (1988) have shown that the scattering layer targets move passively in water currents. Therefore their position in the return current will tend to increase their density towards the south. By contrast, during periods of north-east winds, it is noticeable that the scattering layer beneath the northern fixed station strengthens appreciably. The other structures noted in the scattering layer, such as the cross-loch tilts, are consistent with the circulation of the surface drift due to Coriolis forces diverting the wind drift to the right (George, 1981), i.e. to the southern shore in a south-west wind.

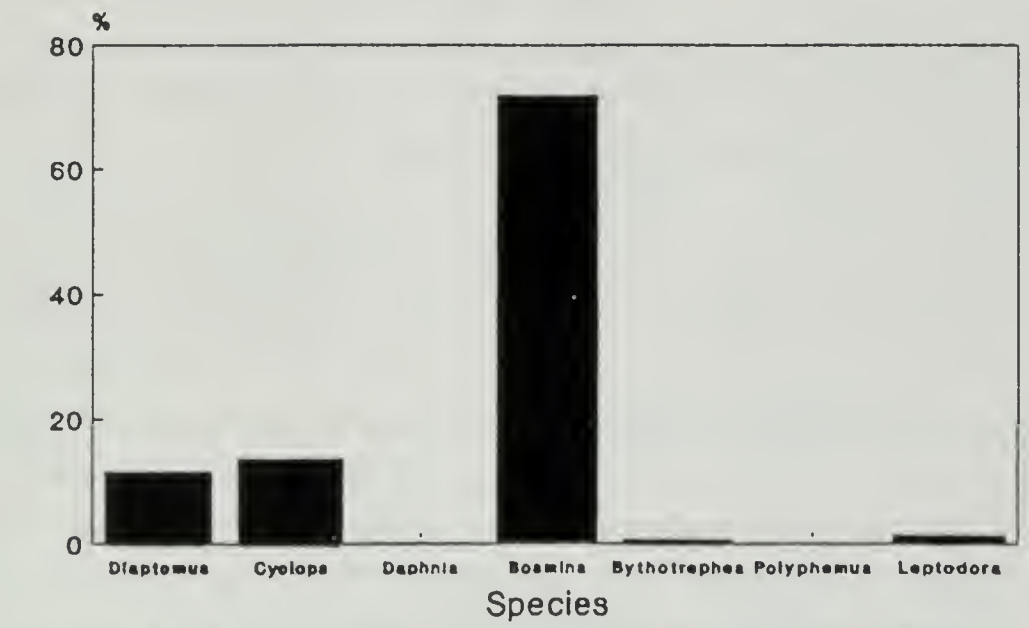
Figure 13

Optical Plankton Counter

a.



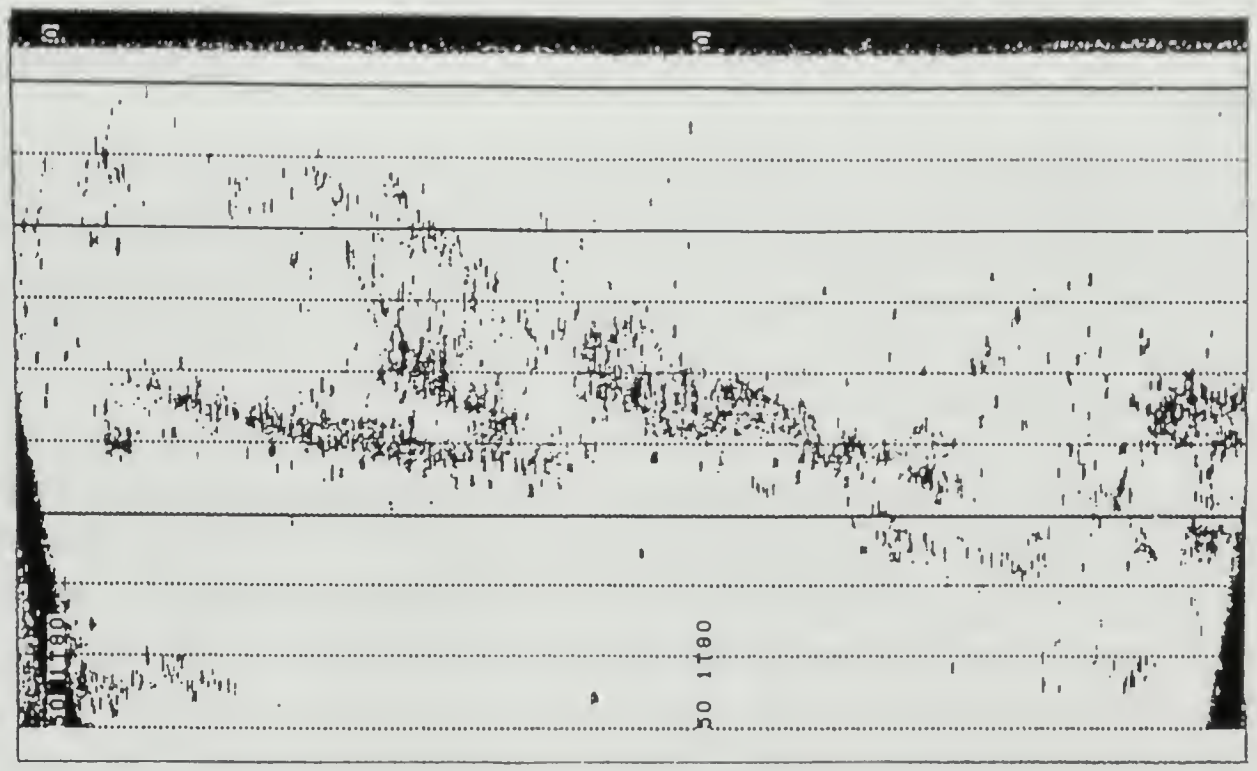
b.

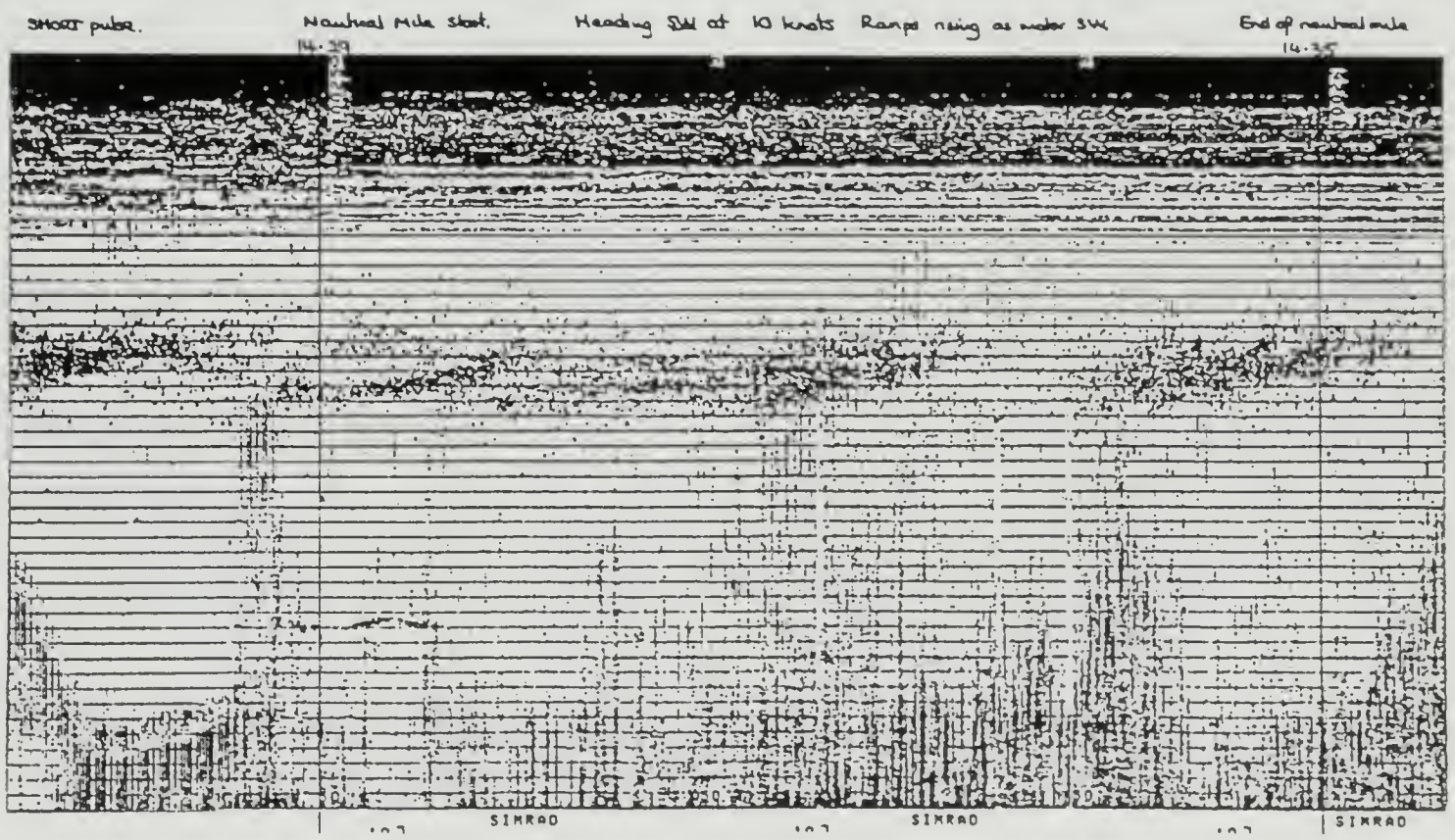


Particle numbers do increase in scattering layers, but high counts can occur without acoustic reflections. The percentage of *Bosmina* at the greatest depths is remarkable. Left is to 100 m and right is to 50 m.

Figure 14

Scattering Layer Structures





The scattering layer is frequently structured. Tilts across the loch (above) and 'ramps' along it (below), may be caused by internal waves and 'mixing' events.

The 'ramps' are of interest, and may represent some form of internal mixing 'fronts' or a reaction to vertical movements induced by internal waves.

Summary

Hydroacoustic *in situ* target strength assessment techniques have been applied to the pelagic zone of Loch Ness. The bulk of the targets are distributed down to the thermocline at densities from 300/ha to 1,000/ha. Over 80% of these targets are of very small size, forming a distinct scattering layer. In contrast to the larger fish, this layer makes nightly migration to the near surface.

The various hydroacoustic systems give different target strengths for the small scatterers, between -75 dB and -57 dB, possibly due to a resonance phenomena. The disparity of target strength is much less for the larger size classes. The identity of individuals comprising the layer is discussed, and juvenile Charr together with chironomids are suggested.

Over 80% of the zooplankton standing crop are copepods which make pronounced diurnal vertical migrations.

The cladoceran *Daphnia*, which is a main food source for the pelagic Charr, does not migrate to the same extent, and perhaps this accounts for the lesser migration shown by the larger fish.

Bosmina, a small cladoceran filter feeder, exhibits no vertical migration, and is often found deep within the thermocline and below it. It is speculated that the cladocerans, particularly *Bosmina*, may utilise allochthonous organic material through the microbial element of the plankton.

There are consistently larger numbers of fish in the South Basin, and greater zooplankton densities are sometimes associated with this. This is a paradoxical observation, since George and Jones (1987) had previously established that conductivity and chlorophyll-*a* concentrations were greater in the north. Again, it is suggested that this is due to allochthonous inputs.

It has been noted that the scattering layer can be more dense in the North Basin with north-east winds, and it is suggested that this results from the individuals spending most of the time in the deeper return current caused by the surface drift. Structures, such as tilts and ramps, in these scatterers show the close association of

physical events in the vicinity of the thermocline with the distribution of the scattering layer.

Acknowledgements

Most of our material has resulted from the efforts of volunteers aboard the Loch Ness and Morar Project vessel *Ecos*, owned and skippered by Mr. John Minshull. We also acknowledge the support of the Loch Ness District Salmon Fisheries Board, and particularly Mr. W. Hastings, the bailiff.

The Simrad company has loaned most of the acoustic equipment, and we are also grateful to the crew of this company's demonstration vessel *Simson Echo*. Particular help was given by Mr. Barry Pardey, Mr. Erik Stennerson and Mr. David Wilson. Dr. Torfin Lindem operated the H.A.D.A.S. system.

D.A.F.S. Aberdeen assisted for some days in August 1988 with their trawler *Goldseeker*, and Dr. Richard Ferro has also made material available from trawling trials aboard *Calanus* in 1992.

Invaluable advice has been given by Dr. J. Simmonds of D.A.F.S. and Dr. Annie Duncan of Royal Holloway College. Special thanks are due to Mr. R.A. Bremner of the Official Loch Ness Exhibition Centre for his continued support and provision of a headquarters for the Loch Ness and Morar Project.

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Received June 1993

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FISH HABITATS IN LOCH NESS

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Introduction

Obtaining reliable ecological data on the fish species living in a large water body the size of Loch Ness is no easy task, and depends upon employing a variety of sampling methods. Apart from sampling difficulties associated with the size and depth of this water body, live capture by means of seine-nets, trawl-nets and tow-nets exerts a simpler mechanical selectivity within the area of collection than do passive techniques using gill-nets or fyke-nets, with which more complex behavioural selectivity plays a bigger role.

The above conventional fish capture techniques were used in Loch Ness from 1988 onwards at sites indicated in Figure 1, and each method was more appropriate for some fish habitats available in Loch Ness than for others (Figures 2a and 2b), thus introducing another level of selectivity. To capture fish in the profundal zone, unconventional methods had to be adopted, such as setting gill-nets at 200 m depth with their lead-line resting on the bottom sediment. The aim of this paper is to add the more recent results, from a greater variety of capture methods, to the fish habitat picture published by Shine and Martin (1988).

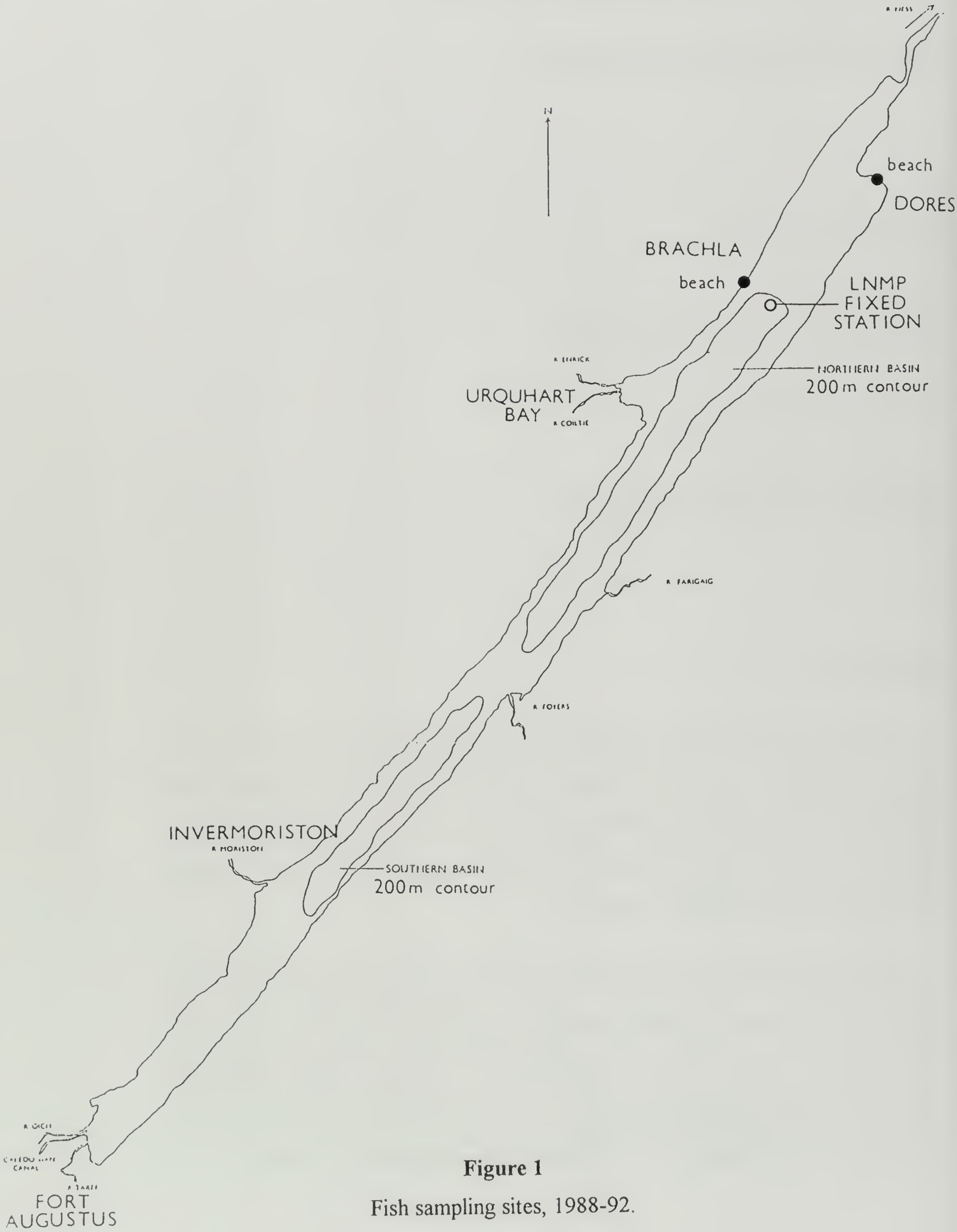

Figure 1

Fish sampling sites, 1988-92.

Methods

Pelagial Habitat

The Loch Ness and Morar Project (L.N.M.P.) gill-net series used to sample the pelagial habitat consisted of five nets between 20 and 25 m long, 1.25 m deep, and with mesh bar sizes of 20 mm, 25 mm and 30 mm, giving a total length of 115 m and a fishing area of 143 m^2. These were suspended on the L.N.M.P. mooring rope in the North Basin opposite Brachla (see Figure 1), in mid-loch between 20 and 30 m depth, in order to span the scattering layer (Shine and Martin, 1988). During the July-August 1991 series, the nets were exposed on fifteen dates, during daylight hours, at night or over 24 hours.

In October 1991 and May 1992, six gill-nets (30 m x 6.0 m; with 15.5 mm, 25 mm and 30 mm mesh sizes) belonging to Royal Holloway University of London (R.H.U.L.) were suspended on the same L.N.M.P. mooring rope, at depths between 20 and 30 m, to encompass the scattering layer which had been detected acoustically. This net series was 180 m long, and had a fishing area of 1,080 m^2. In October 1991, gale force winds prevented the collection of the nets after 24 hours and they were left for four days. The same nets were left on two occasions for 24 hours in May 1992, when the weather was calmer. Also during May 1992, an ichthyoplankton tow-net of 1.0 m diameter and with a 1.0 x 1.7 mm mesh size was towed at three knots within the scattering layer at about 24 m depth for two hours.

On two occasions, in August 1988 and November 1992, the Department of Agriculture and Fisheries for Scotland's (D.A.F.S.) vessel operated a trawl-net in the South Basin at mid-water depths down to 30 m. The August sample was collected using a sprat-trawl with a 12 mm mesh cod-end and a 6.0 m mouth opening (four hauls totalling four hours of trawling). The November sample was collected in the fine-meshed cod-end during trawling trials between Fort Augustus and Urquhart Bay.

Sublittoral Habitat

During December 1992, the L.N.M.P. gill-nets together with some Greer gill-nets (bar sizes 19-30 mm and area 121 m^2, giving a total area of 264 m^2) were set to sample sublittoral depths of 15-25 m off Brachla. The nets were set parallel to the shore with their lead-line resting on the bottom sediment. The same technique

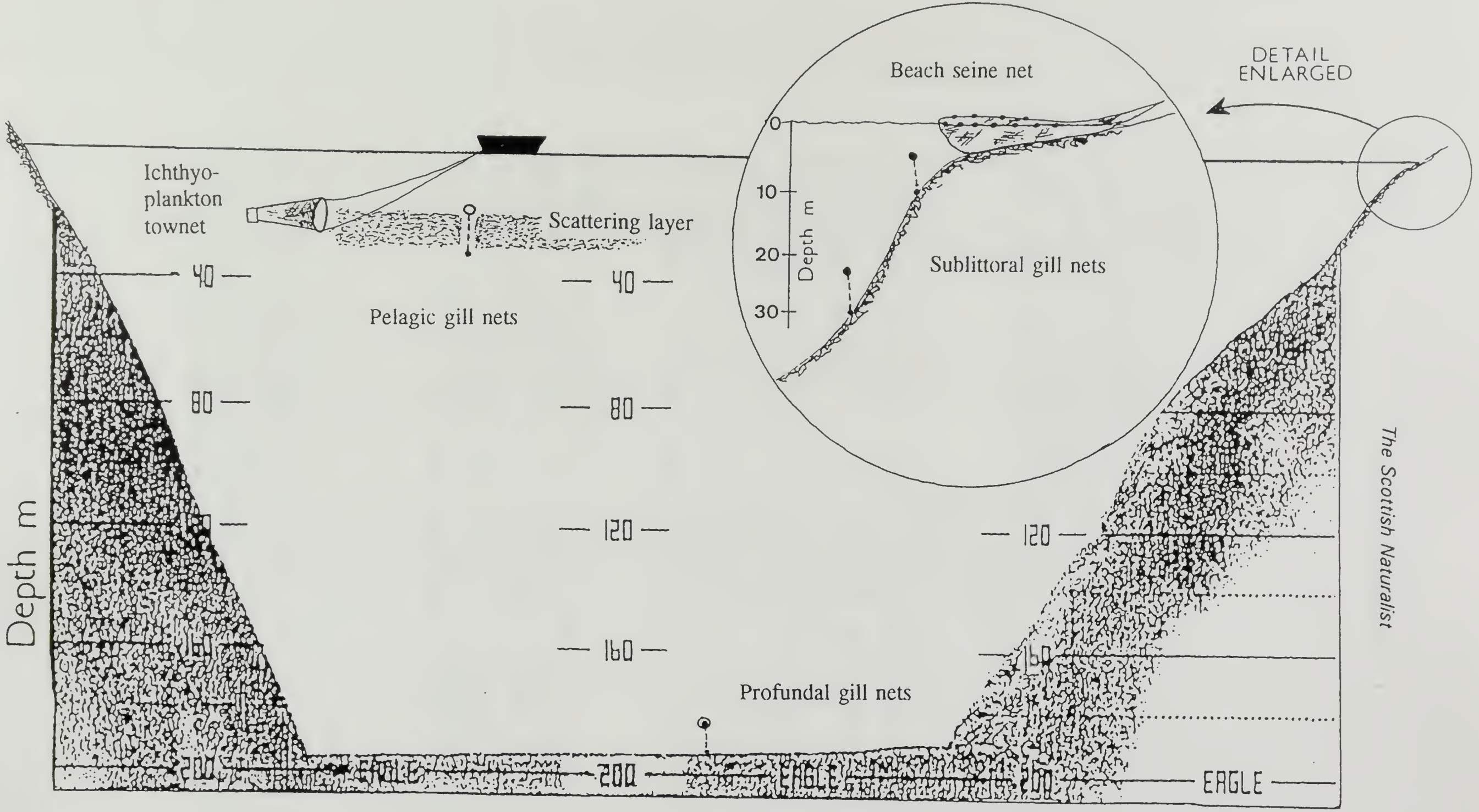

Figure 2a

Transverse cross-section of Loch Ness,
showing position of sampled fish habitats and the sampling gear used.

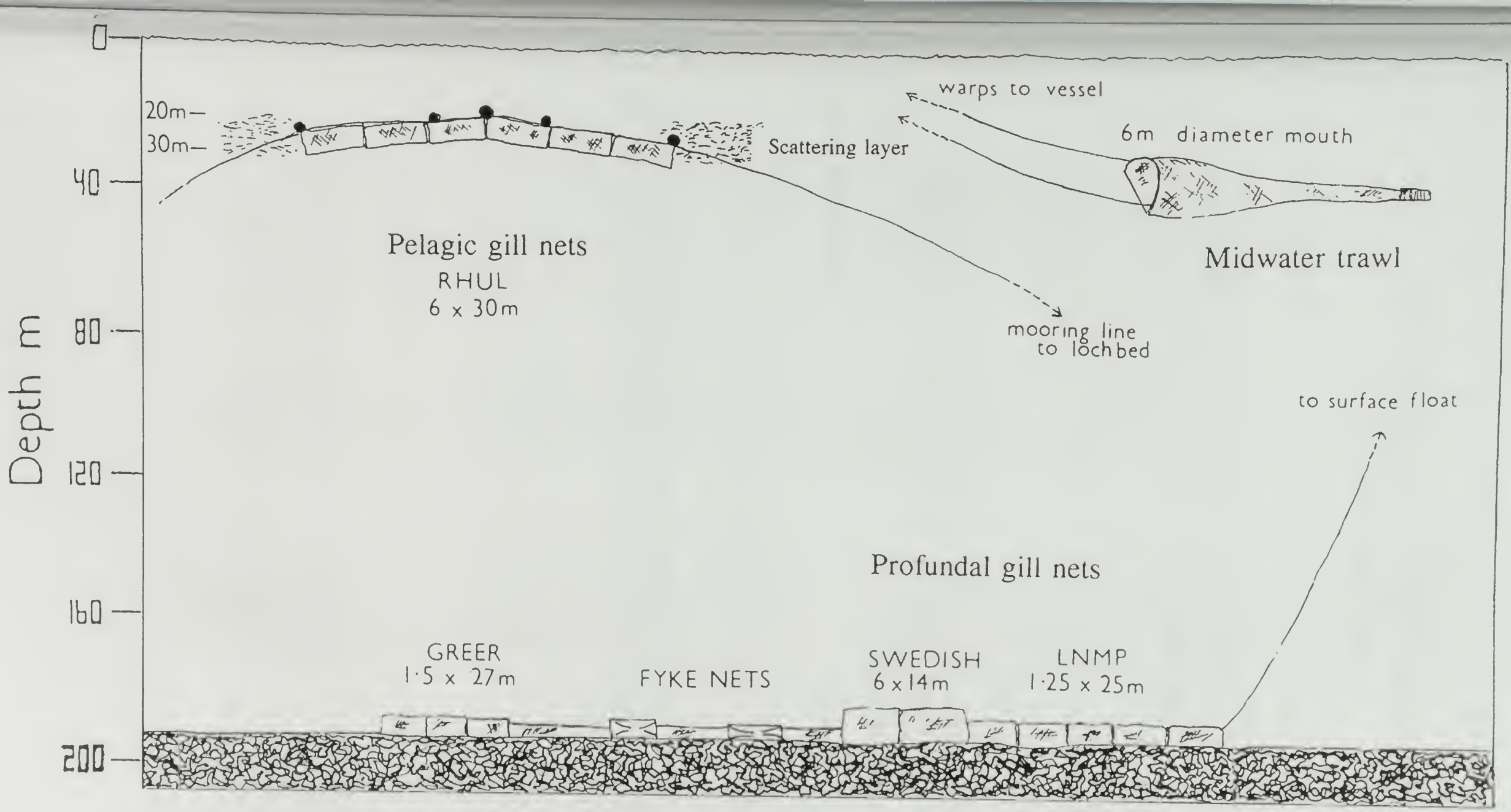

Figure 2b

Longitudinal cross-section of Loch Ness,
showing position of sampled fish habitats and the sampling gear used.

Table 1

Total Fish Captures in Loch Ness, 1988-1992

Arranged under Habitat Zone

ZONE	SPECIES	NUMBERS	LENGTHS (cm)
Littoral	Charr	1	11.0
(0-10 m)	Brown Trout	29	08.0-21.0
	Salmon	4	08.0-11.0
	Stickleback	214	02.7-06.1
	Minnow	21	03.0-06.5
	Eel	3	28.0-36.0
Sub-Littoral	Charr	55	12.0-28.0
(10-30 m)	Brown Trout	95	11.0-36.0
	Sea Trout	8	16.0-45.0
	Salmon	1	39.0
Pelagial	Charr	181	03.0-28.0
(0-40 m)	Brown Trout	29	04.6-57.0
	Stickleback	52	03.9-07.0
	Lamprey	1	05.5
Profundal	Charr	16	04.0-28.0
(180-220 m)			

The full details, including information on the type of nets used, dates of catches, etc, are lodged in the archives of the Loch Ness and Morar Project, where they can be consulted on request.

was used to collect the fish as in the Table headed 'Littoral Netting 1984' in Shine and Martin (1988: 148). On a few occasions, a gill-net (0.5 m high and 200 m long, with a bar size of 15 mm) was deployed down the loch walls from depths of 30 m to 200 m in order to sample any fish present.

Profundal Habitat

The same series of gill-nets were used to sample the fish inhabiting the profundal at 200 m depth, both in Shine and Martin (1988) and in subsequent sampling (Figure 2). The nets were set with their lead-line resting on the bottom sediment. Occasionally, additional gill-nets or fyke-nets were added (Figure 2b). More nets were deployed during the five dates in 1991 (396 m^2) than during the seven dates in 1988 (35-135 m^2), which gave a better success rate and fewer occasions with zero catches.

For comparative purposes a gill-net series, consisting of both the Greer and the 0.5 m high and 200 m long nets, combined with a series of fyke-nets, were set in Loch Morar in August 1992 for two days at a depth of 275 m, but with no fish caught.

Littoral Habitat

During May-June 1992, another technique was employed to sample littoral fish during the day and night. An R.H.U.L. beach seine-net, 15 m long and 2.5 m deep with 1.0 cm mesh size, was laid parallel to the shore-line and about 15-20 m out into the water. After setting the net, the two ends of the net were pulled gently, symmetrically and quietly by rope. Particular attention was paid to the lead-line in order that it be pulled close to the bottom. The area sampled per haul was calculated according to Kubecka and Bohm (1991) to be 80 m^2 for beaches near Brachla (29th/30th May 1992) and 117 m^2 at Dores Beach (6th/7th June 1992). In all, fourteen hauls were taken and all 272 fish caught were released within fifteen minutes of capture, after measurement and removal of scales for ageing.

Results and Discussion

The same seven species of fish were recorded for Loch Ness during this period of sampling as were recorded by Shine and Martin (1988). This is the same number as given by Maitland and his colleagues (Maitland, 1981), who included Pike *Esox lucius*, but not Minnows *Phoxinus phoxinus* which were first recorded

for Loch Ness in 1985-87 (Shine and Martin, 1988). Pike were not captured during the period 1988-92, although some were caught in the sublittoral in previous years. Maitland (1981) also identified his lamprey as the Brook Lamprey *Lampetra planeri.*

Pelagial Habitat

The numbers and sizes of fish species caught by the various collecting methods are given in Table 1. During fifteen deployments between July and September 1991, the L.N.M.P. gill-nets suspended at about 20-30 m depth caught 33 Charr *Salvelinus alpinus* and a few Brown Trout *Salmo trutta.* There were two size classes of Charr, with modal lengths of 16 cm and 26-27 cm. All were adults, with 24 females and ten males. The average catch per unit effort was 2.0 fish per 24-hour exposure.

In October, when the R.H.U.L. gill-netting (1,080 m^2) was left fishing between 20 and 30 m depth for four days, there was a large catch of 17 Charr, ten of which were juveniles (<12 cm fork length), and 23 adult Brown Trout up to 2.0 kg in weight, ten of which were Ferox Trout. It seemed likely that the Trout were attracted to the captive Charr, since some Trout were trapped within inches of the Charr, some of which had been chewed. Fewer fish, and only Charr of a similar size range, were caught during a 24-hour exposure of the same nets at the same site in May 1992. Most of these Charr were adults, and some were mature - one female with large eggs in the ovary and one male with large testes.

Both fish catches by the D.A.F.S. vessel using a mid-water trawl in the South Basin are intriguing on two counts. Both the August 1988 and the November 1992 trawling collected both Three-spined Sticklebacks *Gasterosteus aculeatus* and very small Charr from the full pelagial in waters down to 30 m depth. The collection of as many as 50 Sticklebacks in November 1992 is a surprising record, which should be investigated further because of its implications for acoustic studies (Kubecka, Duncan and Butterworth, 1993). Both D.A.F.S. trawl hauls captured large numbers of Charr, some of which were the smallest Charr (lengths of 3.0, 4.5 and 5.0 cm) so far recorded from Loch Ness, or indeed, as far as we are aware, from the pelagic of any Scottish loch.

Mr. R.B. Greer of D.A.F.S. identified these Charr as young but not larval fish, as might be expected if Loch Ness Charr spawn in the loch in late October/early November. Moreover, larval Charr were not collected in the plankton during

autumn 1992 by tow-netting within the scattering layer, nor during May 1992, as might be expected if the Charr were spring spawners. Further study is urgently needed on the spawning sites and the life cycle of the Charr, which is probably the numerically dominant species in Loch Ness. A tow-net larger than 1.0 m diameter may be an advantage. The question as to whether Charr spawn on beaches in the loch or in local rivers also needs to be resolved. There are no known records, however, of Charr entering any feeder stream of Loch Ness.

The capture of the larval Lamprey in May 1992 is a new pelagial record for Loch Ness, although there is also a recent profundal record (Martin, Shine and Duncan, 1993). It was possibly an individual drawn into the pelagial by wind-induced currents.

Sublittoral Habitat

The collection of mature Charr, whose gonads were 'running' ripe, during December 1992 by the L.N.M.P. gill-net series, set at sublittoral depths of 15-25 m off Brachla, adds some supportive evidence for autumn spawning in the loch, and may indicate the location of one possible spawning site. This was an unusual catch, since regular sampling of the sub-littoral depths between 10 and 30 m with the same nets during May-June 1989 and March-September 1991 normally caught more Brown Trout than Charr.

Profundal Habitat

Sixteen more Charr were caught from the profundal regions on twelve sampling occasions during the 1988-92 period, thus giving an overall total of 29 profundal fish caught since 1982, with standard lengths ranging from 4.5 to 27.9 cm. These were fish with profundal invertebrates in their guts. About a third of these fish were less than 10 cm in length, and about 40% were greater than 19 cm. The fish were caught either by benthic trawling or with an adequate area of gill-netting (about 400 m^2) in deep water.

Littoral Habitat

Night-seining is one of the most cost-effective sampling techniques, which exploits the behavioural tendency of many fish species to migrate shorewards during twilight (Kubecka, 1993). The technique thus samples both the littoral fish, which spend their days in shallow water, as well as the deep or open-water fish,

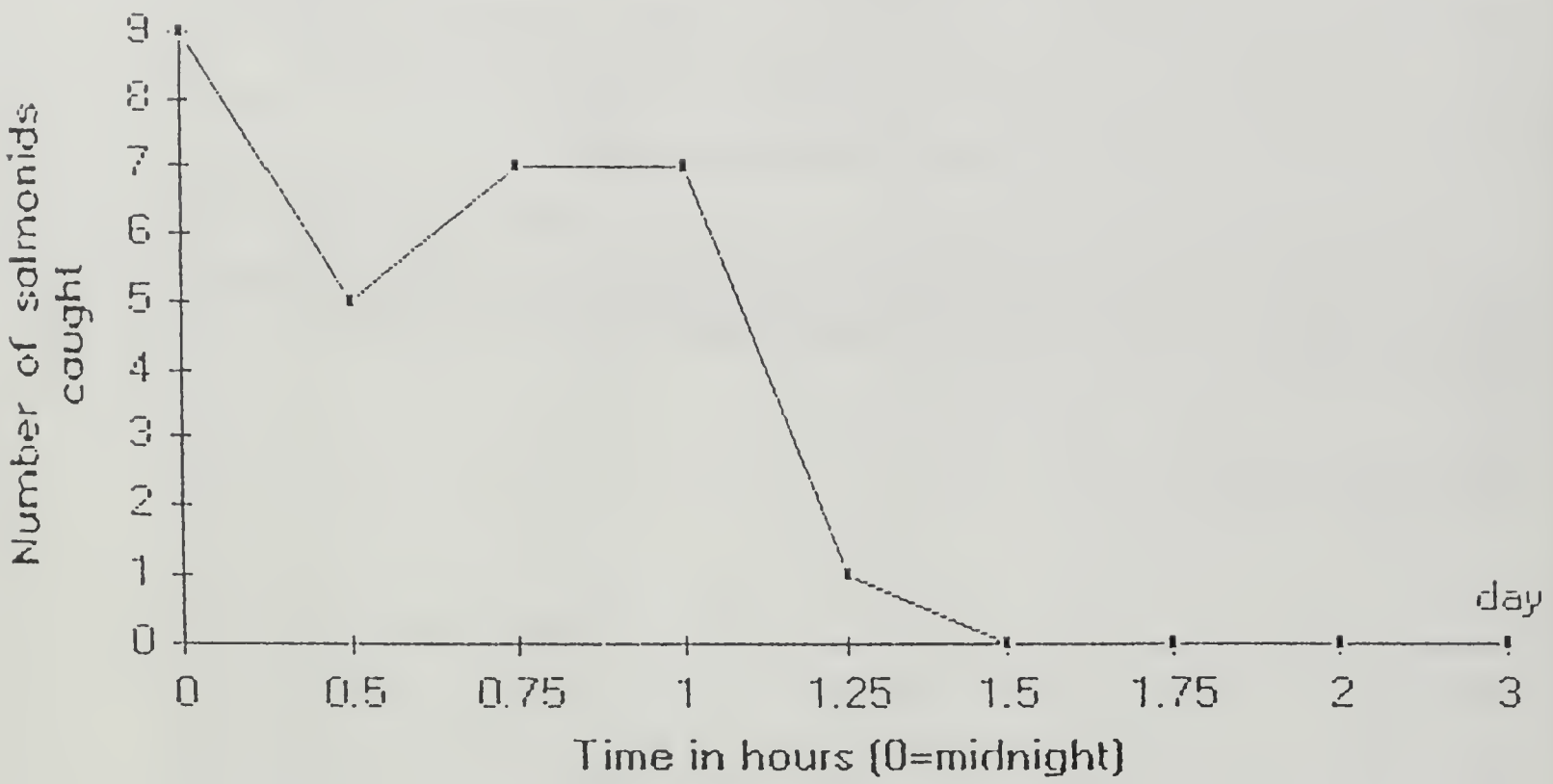

Figure 3

Decrease in numbers of salmonids caught by beach seine-netting, with time after midnight. Pooled results from 30th May and 6th June 1992.

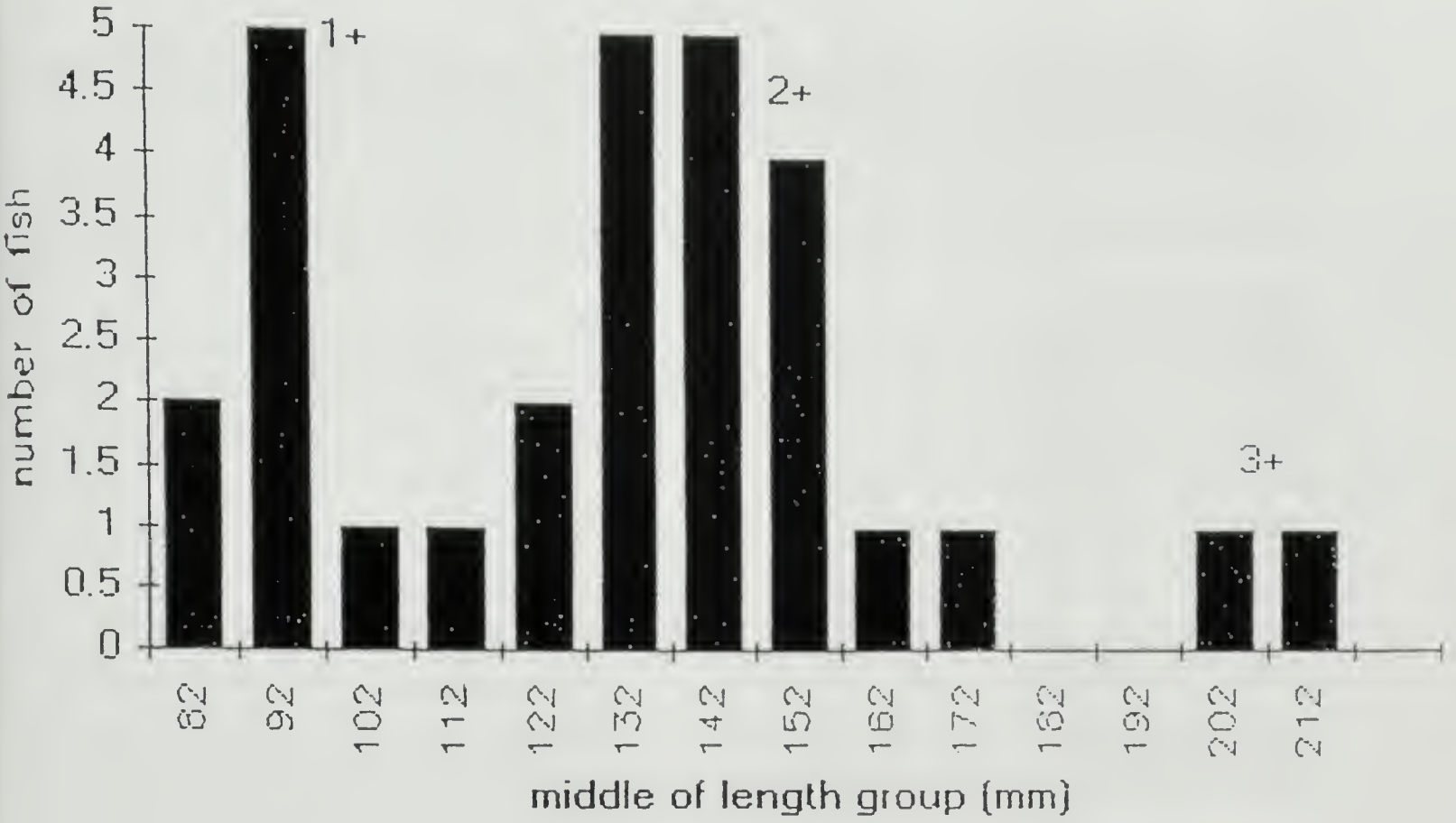

Figure 4

Standard length frequency distribution of Brown Trout caught by beach seining on 30th May and 6th June 1992. Age groups, in years from scale readings, are indicated.

Table 2

Species composition of fish caught by day and night beach-seining in Loch Ness at Brachla beach on 30th May 1992 and at Dores beach on 6th June 1992.

DATE	TIME	TROUT	SALMON	CHARR	EEL	ST'BACK	MINNOW
Night catches							
May 30	24.00	9	0	0	0	10	0
May 30	01.00*	2	0	0	0	0	0
June 6	24.30	1	3	1	0	29	0
June 6	24.45	7	0	0	0	17	0
June 6	01.00	7	0	0	1	16	0
June 6	01.15	1	0	0	1	75	6
June 6	01.30	0	0	0	0	24	1
June 6	01.45	0	0	0	1	11	0
June 6	02.00	0	0	0	0	21	1
Day catches							
Four day hauls		0	0	0	0	0	0
Selective catch		2	1	0	0	11	13
Total fish		29	4	1	3	214	21

* Same site sampled one hour later.

which move shorewards at dusk. It proved valuable in Loch Ness, where it was used for the first time in May-June 1992.

Table 2 lists the species composition of fish caught. During the day, no fish were caught in four out of five hauls, probably because the well-lit shallow water is a dangerous place for small fish. Nevertheless, small fish, such as Minnows, Sticklebacks and even small salmonids, form quite dense shoals in very shallow sites, thus avoiding predation by big fish (see the selective day catch in Table 2).

At night, Sticklebacks were caught in large numbers in every haul, together with small salmonids and Minnows in some hauls. The numbers of salmonids caught increased with 'true darkness', but declined abruply with the advent of 'dawn', which arrives early in the short northern night (Figure 3). It would be advantageous to repeat this exercise when nights are longer.

Although only 29 Brown Trout were caught, Figure 4 shows that three year classes of fish were present, namely 1+, 2+ and 3+. With a bigger net, it seems likely that night shore-seining could be used to establish the ratios of young Brown Trout to young Salmon *Salmo salar* to littoral Charr, which is useful information for understanding the ecology of Loch Ness salmonid populations.

Before embarking on a longer term study, some care should be taken with the size of net used. The number of fish caught is a function of the area sampled quantitatively, and Figure 5 illustrates the relationship between net length and area sampled.

Sticklebacks and Minnows are an important food source for piscivorous salmonids, so any information about their population size structure is useful. Figure 6 shows that three size groups were present in the Stickleback population sampled by shore-seining; these were 31-33 mm, 41-45 mm and 51 mm or larger. Although Sticklebacks cannot be aged by their scales, further study on their growth rates would provide this information.

No Pike were caught by shore-seining in Loch Ness, perhaps because Pike were absent in the sampled areas, whereas the catch per unit effort of small Eels *Anguilla anguilla* (30-35 cm) was high compared with other localities where night-seining has been carried out (e.g. River Thames, Czech and London reservoirs). Both species need further study in Loch Ness.

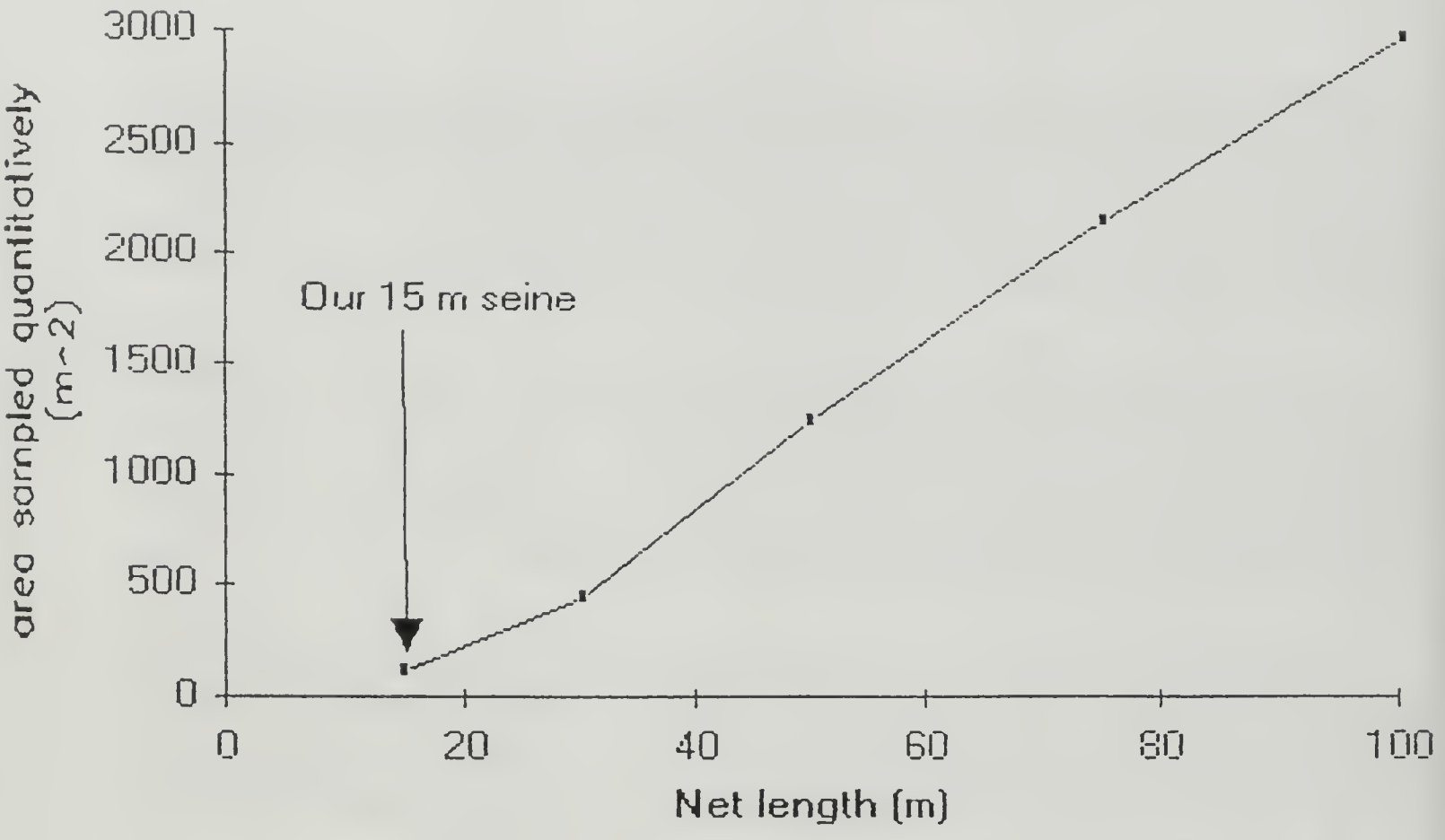

Figure 5

Relationship between the littoral area which can be quantitatively seined at Dores Beach, and the length of the shore seine-net used, calculated for 2.5 - 4.0 m deep seine.

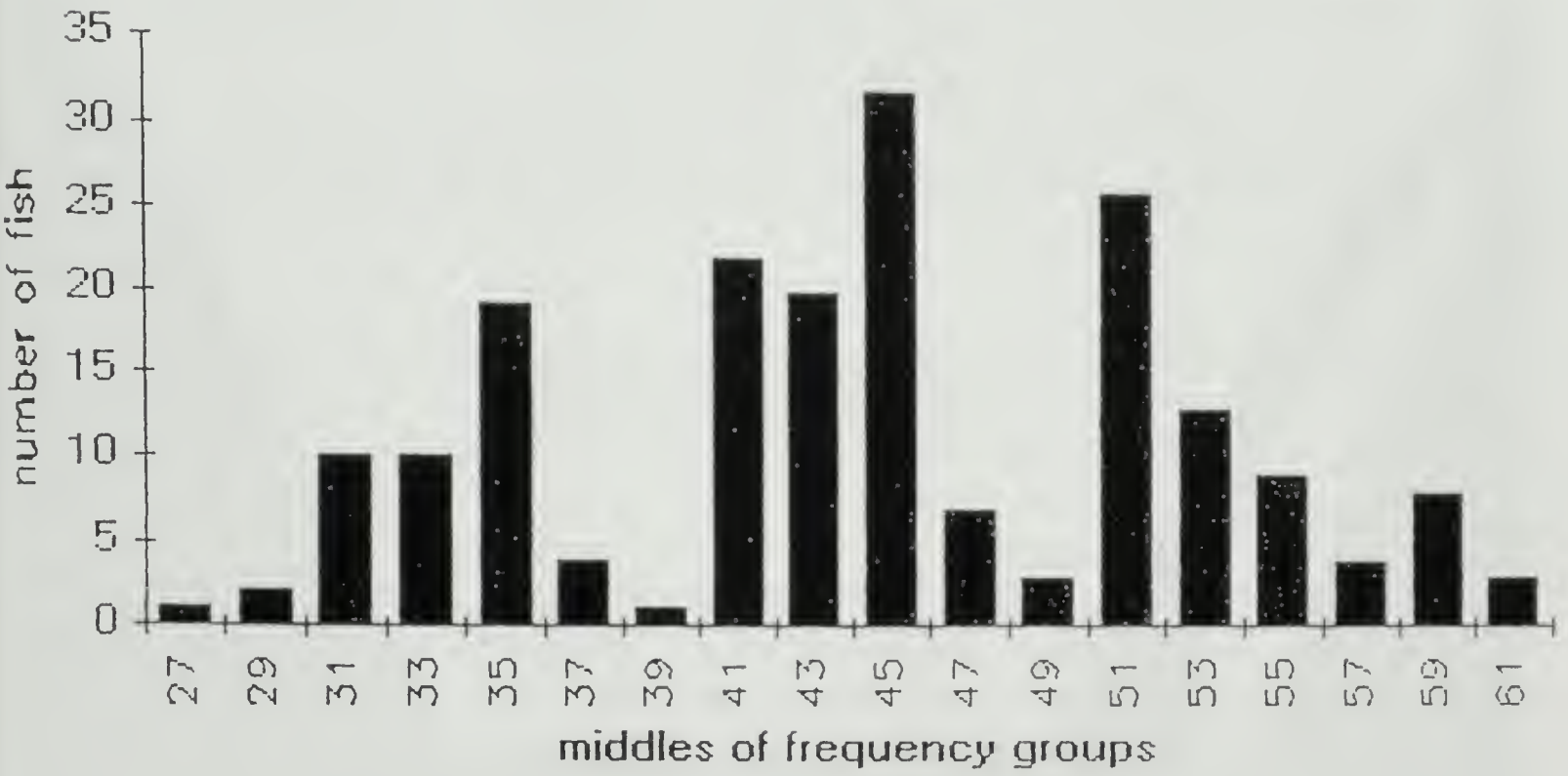

Figure 6

Standard length frequency distribution of Sticklebacks caught by shore-seining on 30th May and 6th June 1992.

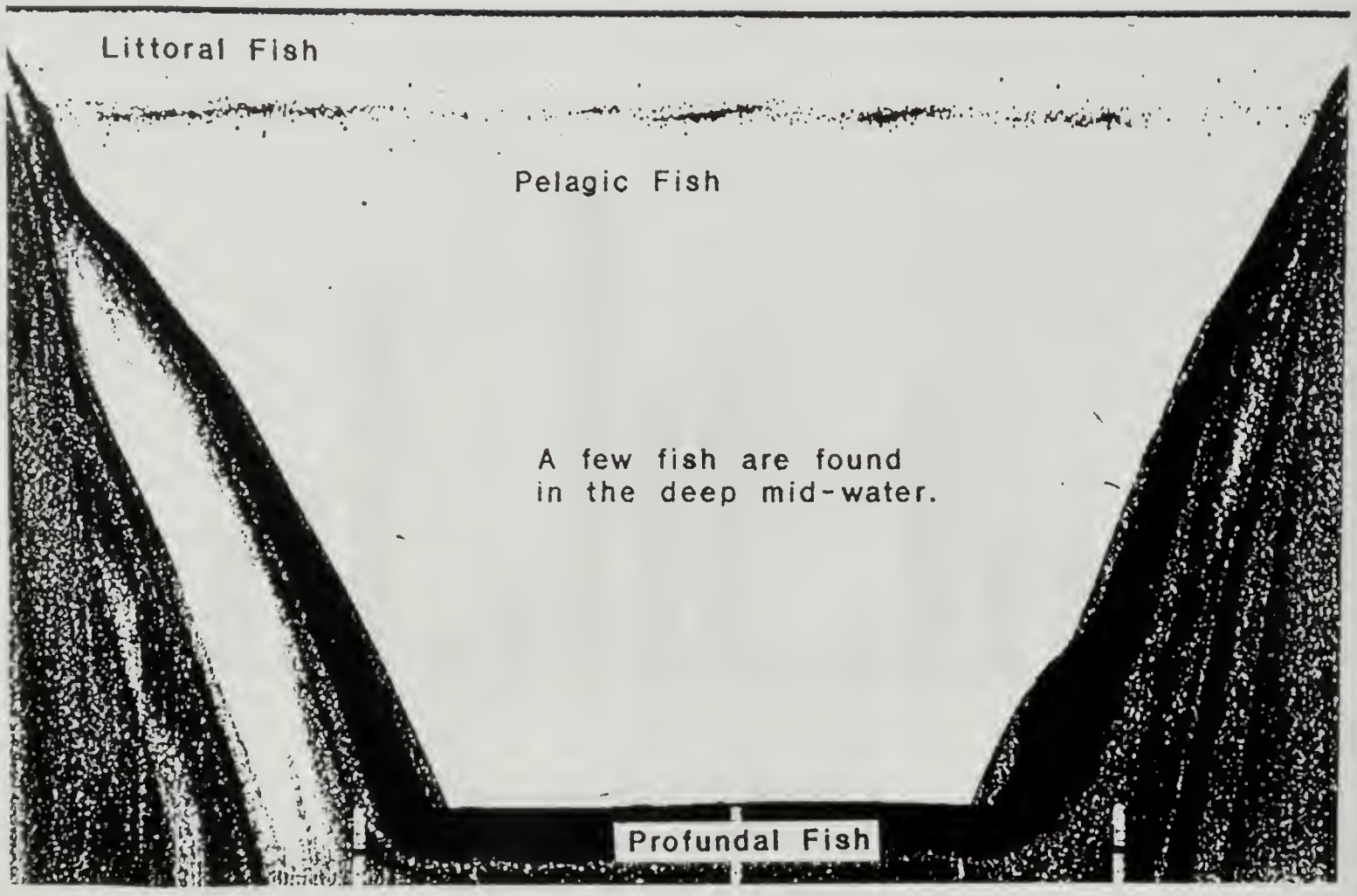

Figure 7

An echo-sounding transect (Simrad EK500 38 kHz) across Loch Ness shows the range of fish habitats. Most of the Trout are concentrated in the littoral. From the sub-littoral, below 10 m, a layer of Charr extends across the pelagic zone. There are generally some echoes from the deep mid-water, but the fish concentration only rises again on the flat silts of the loch bed at 200 m. The invertebrates of this profundal zone support a population of Charr.

Summary of Fish Habitats in Loch Ness

Sampling Loch Ness fish habitats is a difficult task. Table 1 gives a summary of the species composition and sizes of the fish catches in the different habitats of the loch. Charr is the most ubiquitous species in the loch and the most abundant species in the pelagial and the profundal. Brown Trout dominate sublittoral catches with Charr coming second (see also Shine and Martin, 1988), whilst the Three-spined Stickleback is an important species in the littoral and the pelagial (Figure 7).

The various fish habitats were sampled by appropriate methods, which are illustrated in Figures 2a and 2b. At present, depths greater than 50 m in the open water have not been sampled by live capture techniques, and depths between 50-70 m and 200 m were not reached by 420 kHz dual-beam sonar (Kubecka, Duncan and Butterworth, 1993). Since then, however, a 38 kHz split-beam sonar has shown a small number of probable fish targets at these depths, and a greater number on the loch bed (Figure 8). Having established a sampling technology for some of these fish habitats, and with the aid of quantitative echo-sounding (Kubecka, Duncan and Butterworth, 1993; Shine, Martin and Marjoram, 1993), the situation is ripe for studying how the more numerous species, Charr and Sticklebacks, exploit this deep oligotrophic loch, by finding out where they spawn, where their subsequent life-cycle stages live, and quantifying their impact upon the ecosystem.

Acknowledgements

We should like to express our thanks to the Royal Holloway University of London for permission to use the fish sampling equipment, and to the Loch Ness Fisheries Board for permission to try out whether night shore-seining was a useful fish sampling method in one of Britain's largest lochs. We also acknowledge the presence and help of the bailiff, Mr. W. Hastings.

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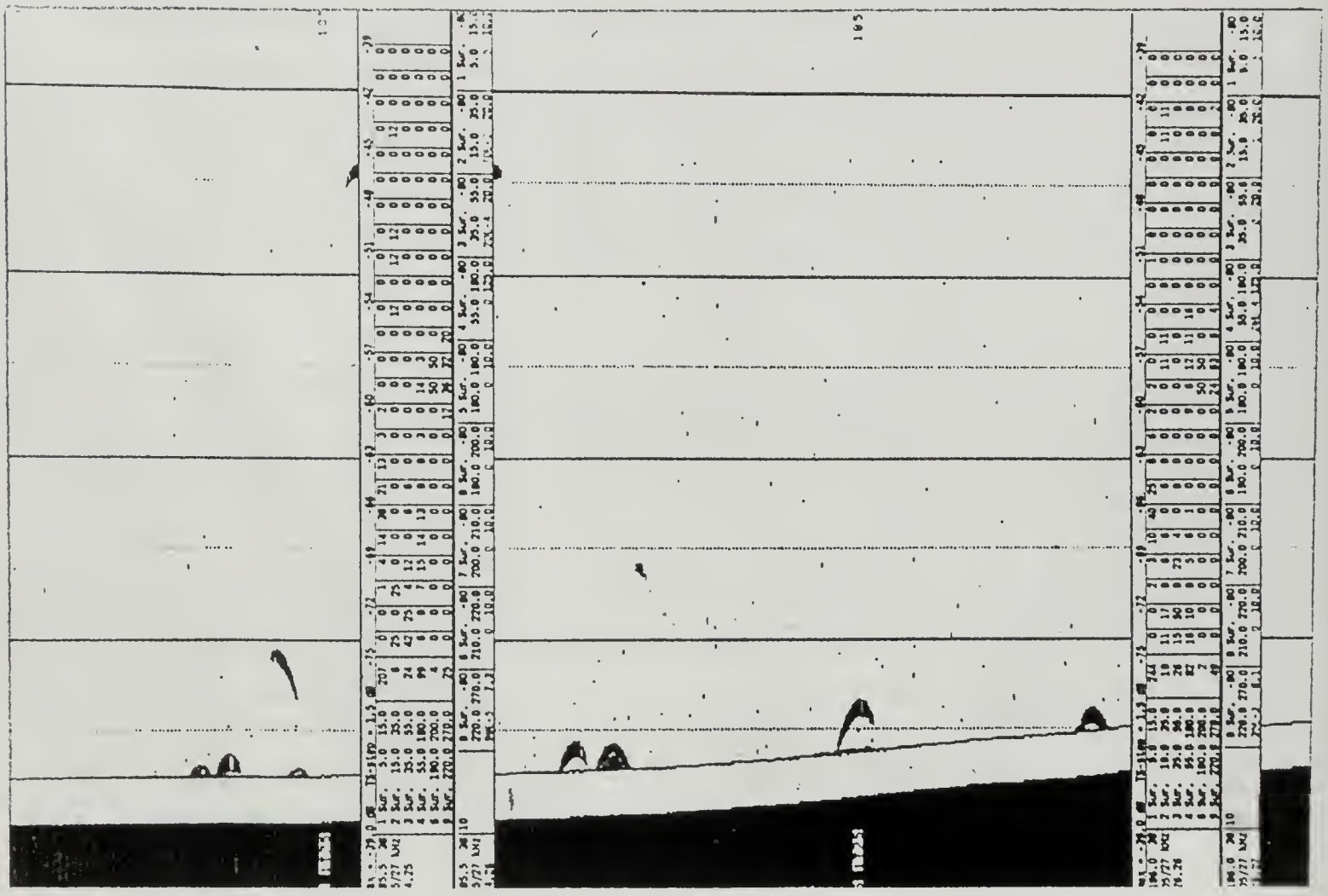

Figure 8

Fish close to the loch bed are difficult to detect acoustically. The bottom expansion facility of the EK500, however, together with the low frequency (38 kHz), allows some fish to be observed.

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Received July 1993

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ALLOCHTHONOUS ORGANIC INPUTS AS AN EXPLANATION OF SPATIAL BIOMASS GRADIENTS OBSERVED IN THE PELAGIC AND PROFUNDAL ZONES OF LOCH NESS

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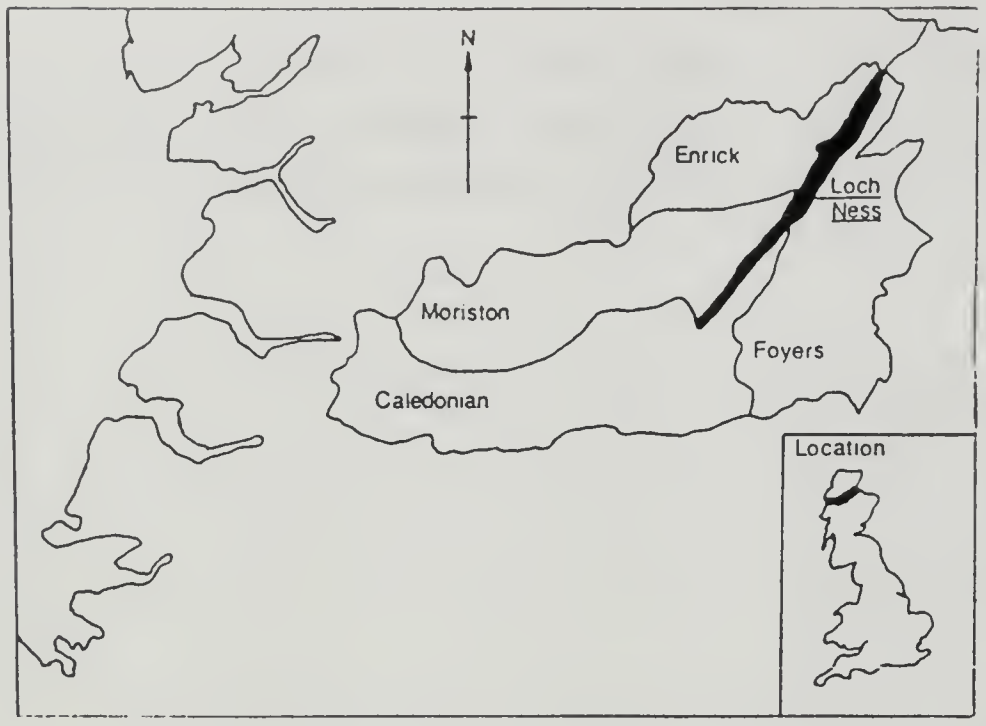
Introduction

A theme recurring throughout the collected papers on Loch Ness appearing in this Volume 105 (1993) of the *Scottish Naturalist* is spatial variation along the 39 km basin of the loch.

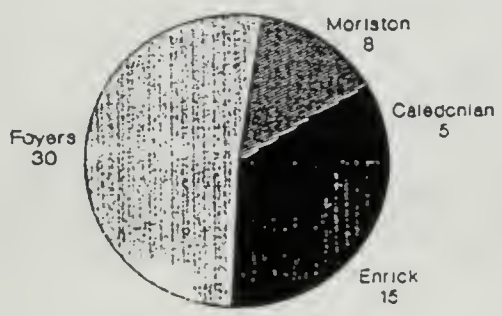
Gradients

George and Jones (1987) first explored gradients in conductivity and chlorophyll-*a* in the five largest Scottish lochs, during the multi-disciplinary study by the Institute of Terrestrial Ecology from 1977 to 1980 (Maitland, 1981); in general, phytoplankton gradients reflected catchment richness. At Loch Ness, all samplings showed increased conductivity and phytoplankton in the North Basin. Figures 1a and 1b clearly show the much larger proportion of base rich rock and arable land in the two northern sub-catchments. Nevertheless, in terms of phosphorus at least, the differences appear small in Jenkins' (1993) Tables.

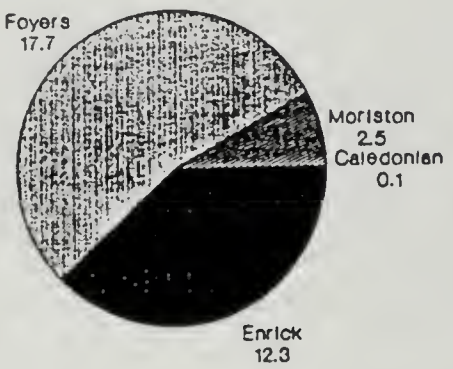
A paradox arose, therefore, in the 1980s, since acoustic observations showed a persistent increase in fish numbers towards the south (Shine and Martin, 1988). Since then, Kubecka, Duncan and Butterworth (1993) and Shine, Martin and Marjoram (1993) have confirmed this, and in the latter case have also observed



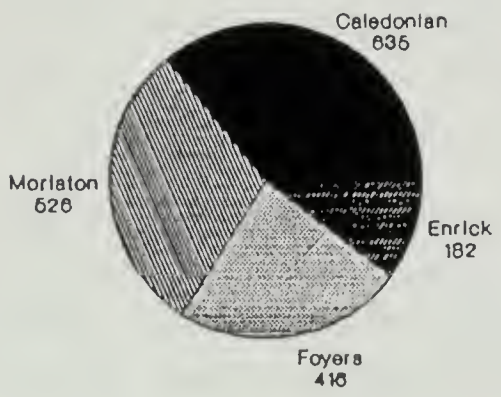
a) Percentage base rich rock in sub-catchments



b) Arable land use (km2) within sub-catchments



c) Sub-catchment areas (km2)



d) Inflow estimates from the sub-catchments m3/s/year

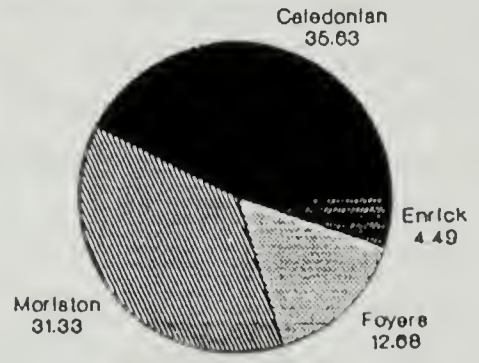


Figure 1

Loch Ness Sub-Catchments.
(After Maitland, 1981)

zooplankton maxima in the south, although this appears to be more wind dependent. A clue to the paradox may lie in the benthos studies.

Griffiths and Martin (1993) note greater ostracod densities in the South Basin. The nematodes, oligochaetes, *Pisidia,* copepods, Cladocera and chironomids described by Martin, Shine and Duncan (1993) also show greater densities in the South Basin.

Core Survey

Bennett (1993), in a 27 core survey, has analysed particle size and organic content along the axis of the loch. The two Basins were found to be clearly divided by a 'sill' of organically poor and higher particle-size sands off the River Foyers (Figures 2a and 2b). On either side of this lie the two deep Basins, of which the South Basin has a 2.0% higher proportion of organic rich sand/silt muds (28.72% - 29.29%) off the river mouths. The organic inputs to the South Basin, however, are actually even higher, since the total sedimentation rate, judged from a marker layer thought to result from the great flood in 1868 (Anon., 1868), is almost twice that of the North Basin. The map (Figure 3) shows the much larger influence of rivers in the narrower South Basin.

Catchment Differences

None of this is surprising when the much larger area of the southern catchments is considered (Figure 1c), or the greater western rainfall in the Caledonian and Moriston sub-catchments. Figure 1d demonstrates how this increases their importance in terms of annual flow.

Mansfield (1992) and Bracewell (1993) have shown that lipids from organic matter in Loch Ness sediments are indicative of higher terrestrial plant detritus from the catchment rather than of autochthonous material. It is therefore proposed that the density gradients observed in fish, zooplankton and benthos may be related to microbial utilisation of the allochthonous inputs dominating the South Basin, as opposed to the low primary productivity which is also limited by light attenuation due to the humic elements of these inputs.

Bacteria Levels

Based upon light extinction and chlorophyll-*a* data, it is estimated that the dissolved organic carbon exudations for phytoplankton cannot sustain the observed bacterial production levels (Dr. Johanna Layborn-Parry and Mr. M. Walton, pers.

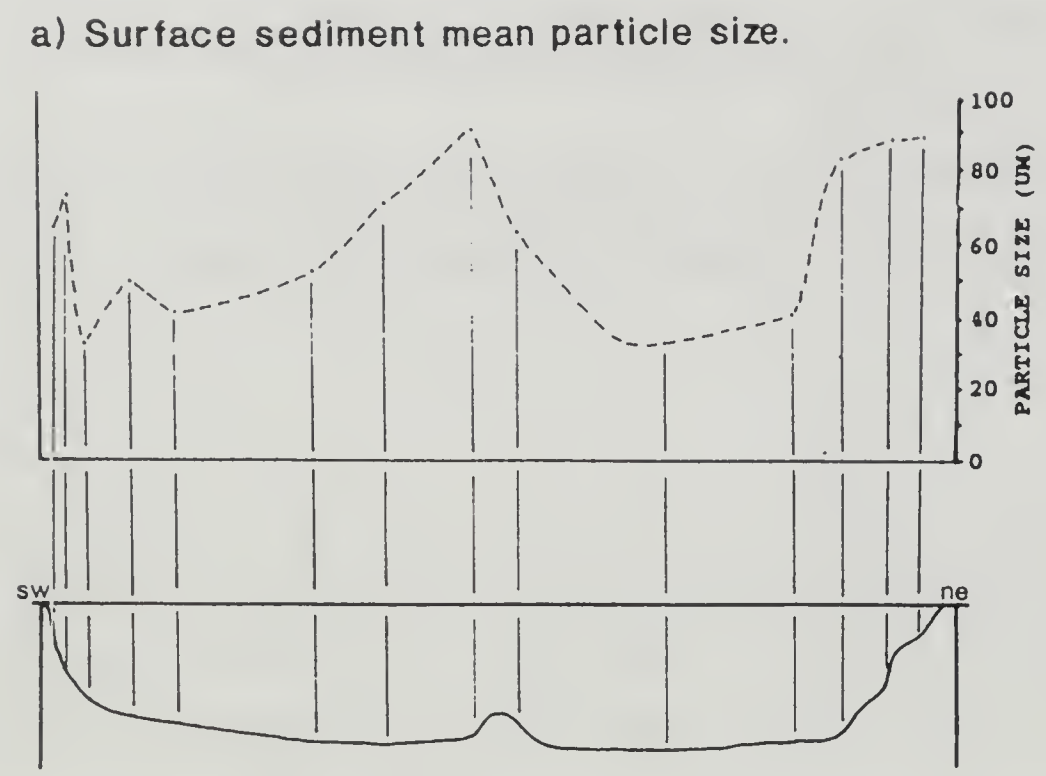


Figure 2

Sediment variation along the axis of Loch Ness.
(From Bennett, 1993)

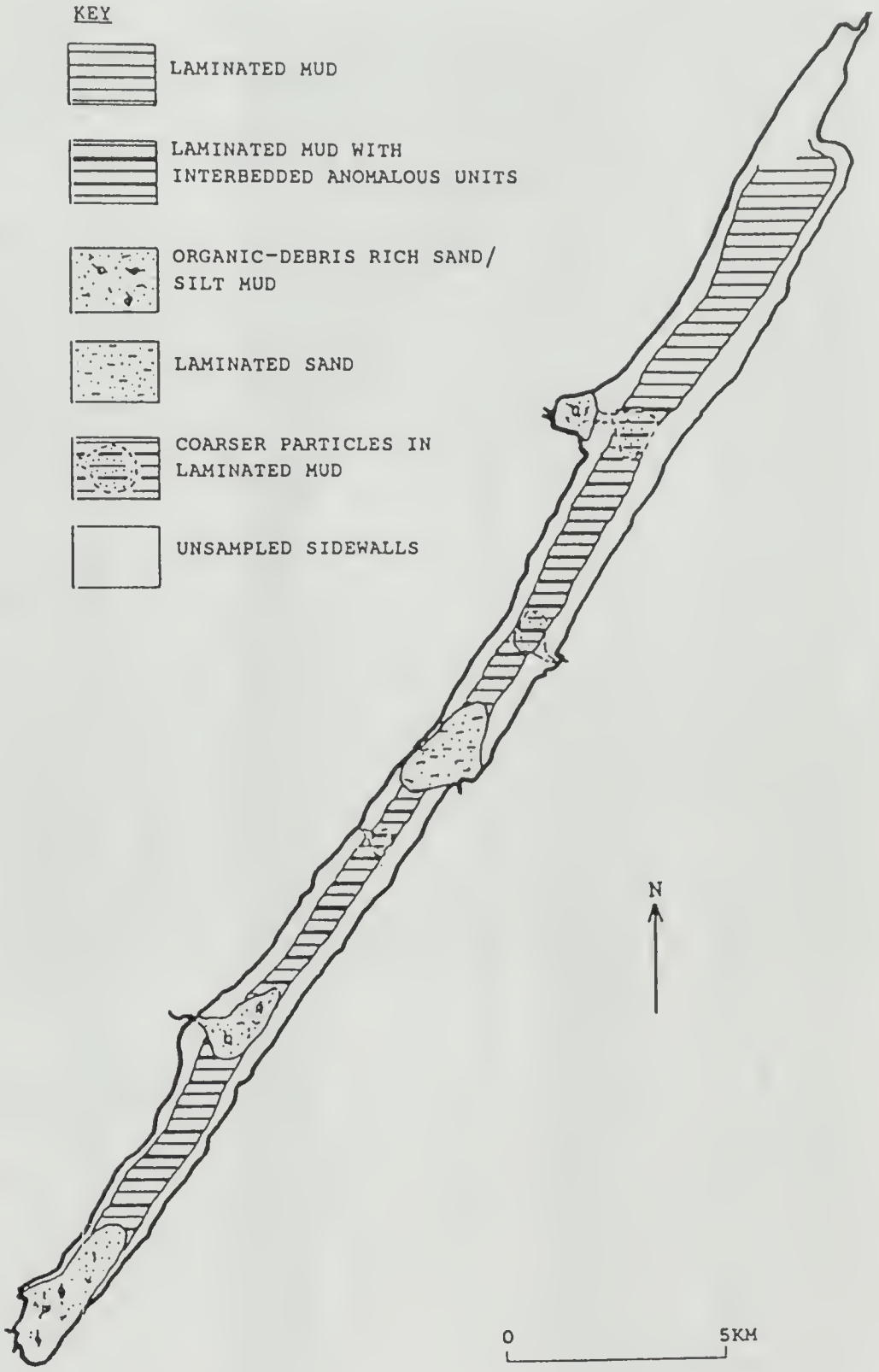


Figure 3

Distribution of sediment types in Loch Ness.
(From Bennett, 1993)

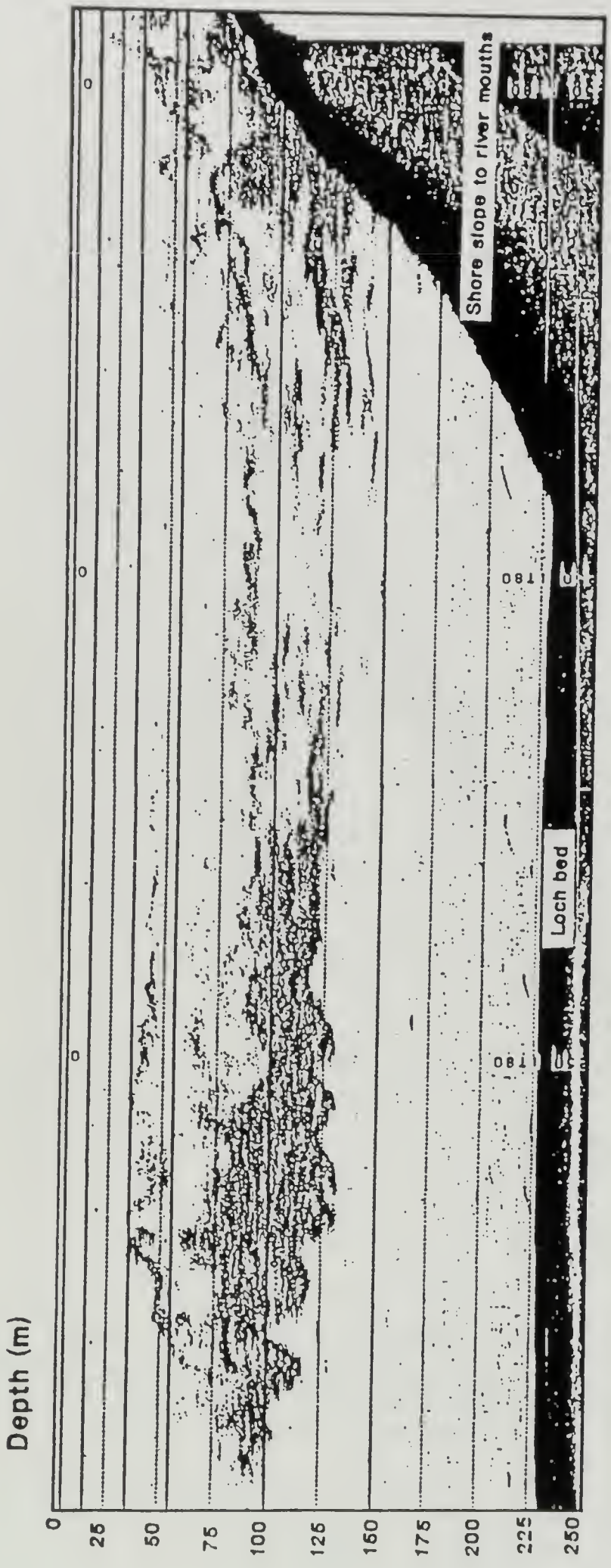


Figure 4

Interflow from river inputs in Urquhart Bay (21st May 1991)

comm.) (Note 1). Also, bacterial numbers are relatively high in the winter when primary productivity is at its lowest but the river flows are at their highest. During one sampling along the loch's axis, bacterial numbers were found to double at the southern end (Dr. R.I. Jones and Dr. Johanna Layborn-Parry, pers. comm.) (Note 2).

Humic inputs, previously thought to be recalcitrant, have recently been shown to play important roles in sustaining bacterial production (Moran and Hodson, 1990). It seems possible that the higher zooplankton, particularly the filter-feeding Cladocera such as *Daphnia* and *Bosmina,* may utilise a microbial food source, possibly through heterotrophic nanoflagellates and ciliated protozoa (Porter, Feig and Vetter, 1983). In this way, allochthonous inputs would find their way to the fish.

Resource Distribution

The way in which inputs distribute their resources is also of interest. Often the river water will be denser than the loch surface water and will deliver the sediment load as an interflow (Figure 4), which may account for the large quantities of non-migrating Cladocera sometimes found in and beneath the thermocline. Once in the water column, the inputs will be vigorously mixed and widely transported by the turbulence induced by shear due to wind stress (Figure 5). However, the deeper return current generated by the prevailing south-west wind will tend to confine inputs to the south.

Physical Considerations

The regularity of the Loch Ness basin, and its orientation south-west to north-east in line with the prevailing winds, renders it particularly physically dynamic. Furthermore, turbulence has been suggested as a mechanism for aggregation of dissolved organic matter (Wotton, 1984; Petersen, 1986). The role of aggregates (known in oceanography as marine snow) is important, since in oligotrophic waters aggregates provide centres of enhanced microbial activity (Caron, Davies, Madin and Sieburth, 1982 and 1986).

In May 1991, while the interflow (Figure 4) was being recorded off Urquhart Bay, the water temperature only varied from 7.9°C at 15 m to 7.0°C at 87 m, but with a suggestion of a weak thermocline at about 80 m coinciding with the interflow depth. A Marine Snow Camera, from the Institute of Oceanographic Sciences, lowered from a fixed station 5.0 km to the north, showed some

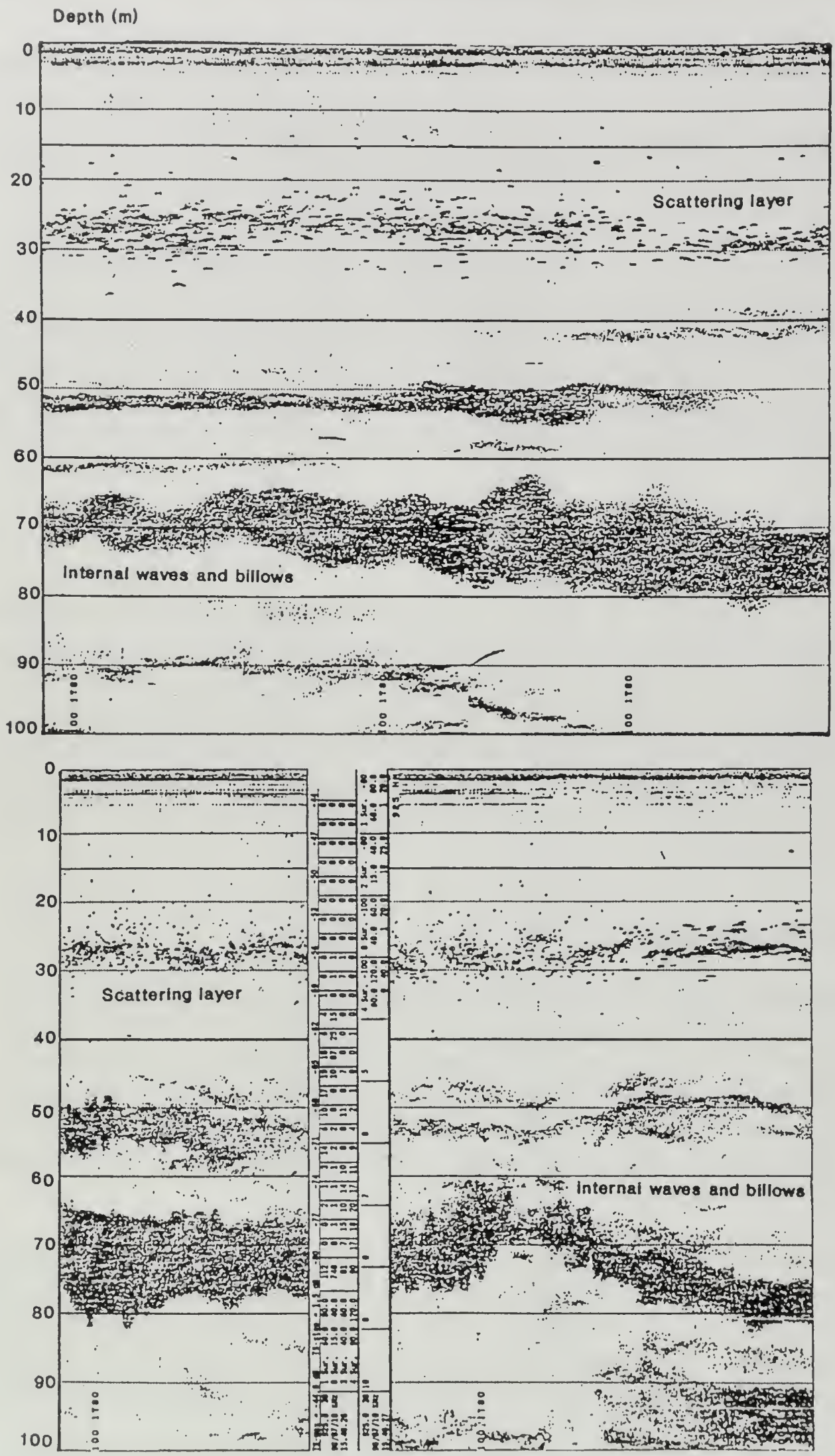


Figure 5

Mixing events due to shear along the axis of the loch, detected on the EK500 (38 kHz) echo-sounder (July 1990).

interesting changes in the distribution of particles (Mr. W. Hillier, pers comm.) (Note 3).

Figure 6a shows the greatest number of particles to be above and within the thermocline at between 60 m and 80 m. There is another smaller increase at 140 m. Figure 6b, illustrating mean particle size, and Figure 6c, illustrating cumulative frequencies, show that the change at 70 m is confined almost entirely to an increase in the population of the largest size category (2.0 mm), which could be zooplankton, and that the change at 140 m involves a relative decrease in the smallest size class (0.5 mm). In terms of diameter, these appear to correspond to a relative increase in particles over 1.5 mm long, and a decrease in particles of less than 1.0 mm long, respectively.

Figure 6d shows the grey level (more particles = lower grey level), and the notable feature is the higher grey level below 100 m, thus indicating much clearer water, probably the hypolimnion. One speculation is that these results may show aggregation taking place and being confined to two areas of possible turbulence.

Conclusion

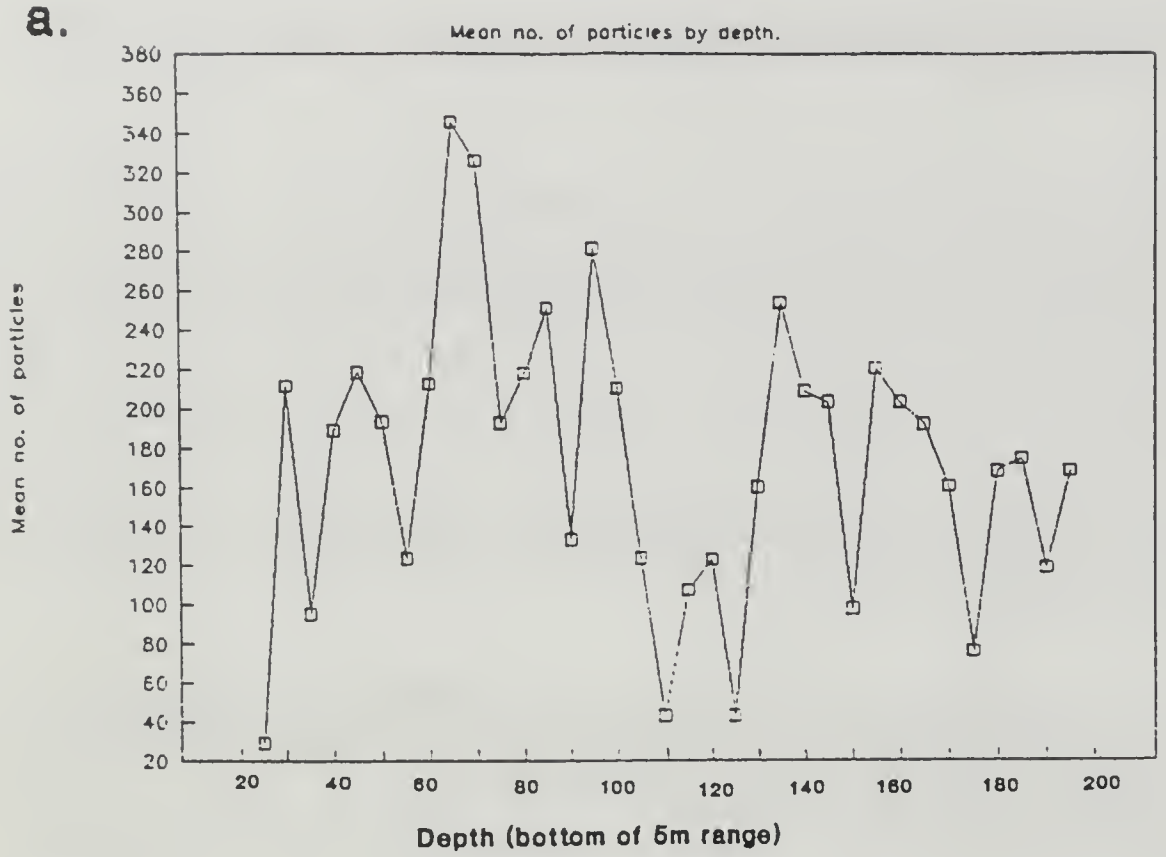
In conclusion, it is proposed that the gradients observed in the density of biota along the loch's length can be ascribed to allochthonous inputs of particulate and dissolved organic matter in the South Basin. These would mostly be delivered to the water column at depth as interflows, where they may remain confined to the belt of turbulence at the thermocline. They would then be transported along the loch through shear, while they are utilised by microbial plankton and passed up the food chain. Thus the cause of the biological gradients is to be found in the sediments and its ultimate effect in the southern fish concentrations.

Notes

1. M. Walton and Johanna Laybourn-Parry: Functional Aspects of the Microbial Plankton in Loch Ness. Paper read at British Ecological Society's winter meeting and A.G.M., University of Lancaster, 15th-17th December 1992.

Johanna Laybourn-Parry and M. Walton: Studies of the Plankton of Loch Ness - The Microbial Loop. Poster paper: displayed at British Ecological Society's winter meeting and A.G.M., University of Lancaster, 15th-17th December 1992; and at Scottish Freshwater Group's 50th Meeting, University of Stirling, 2nd-3rd February 1993. Later published as abstract (Laybourn-Parry and Walton, 1993).

a.



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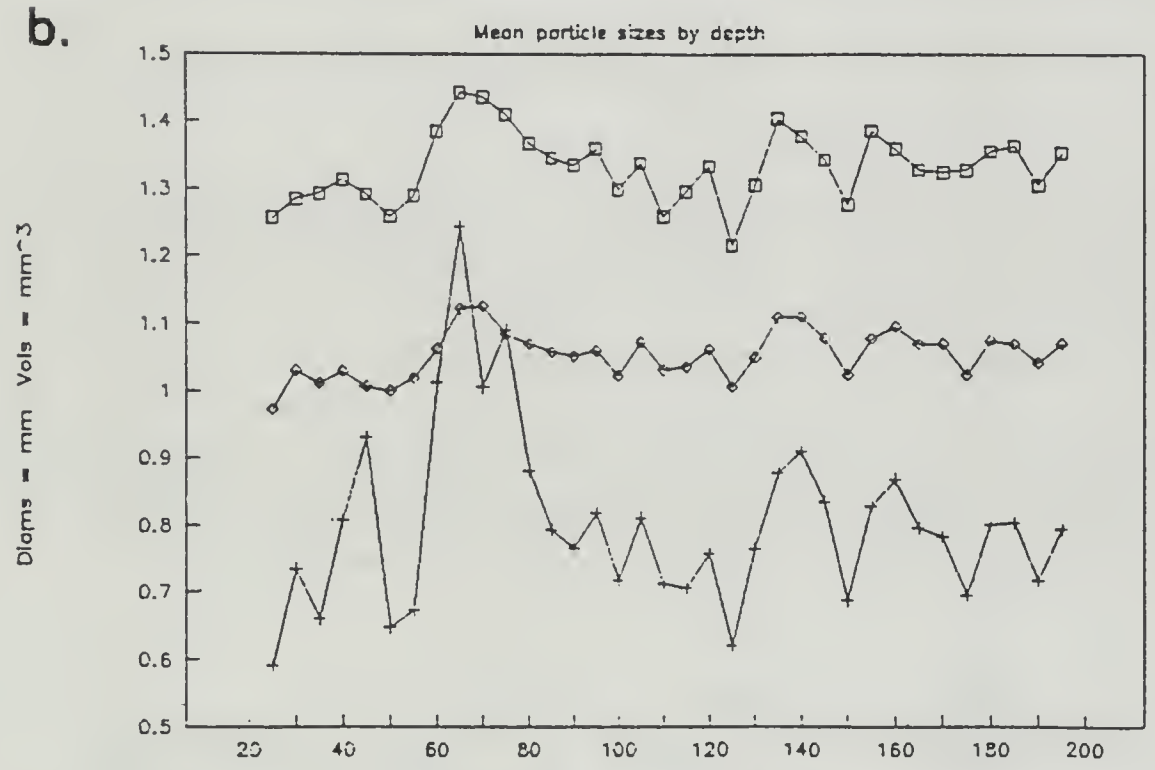


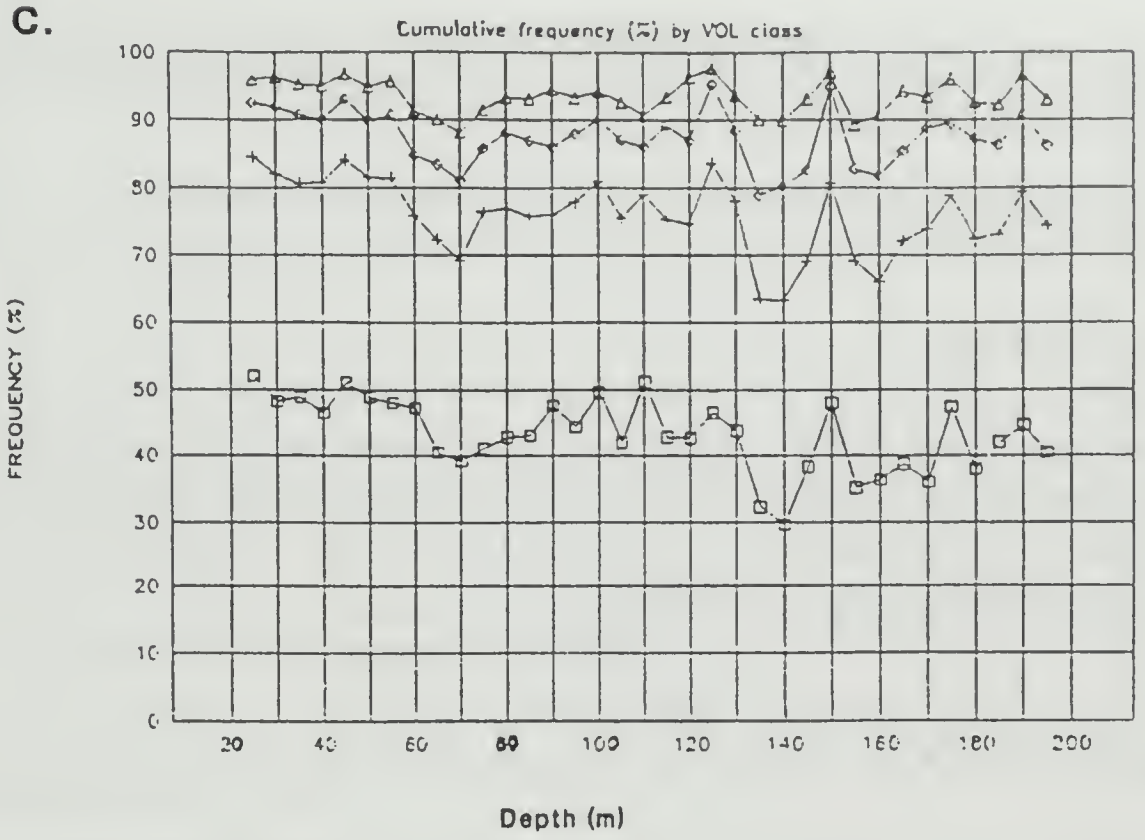
Particle numbers and sizes by depth

DMAX = Maximum diameter
VOL = Calculated corrected for non-circularity
ESD = Diameter of sphere of equivalent volume

Figures 6a and 6b

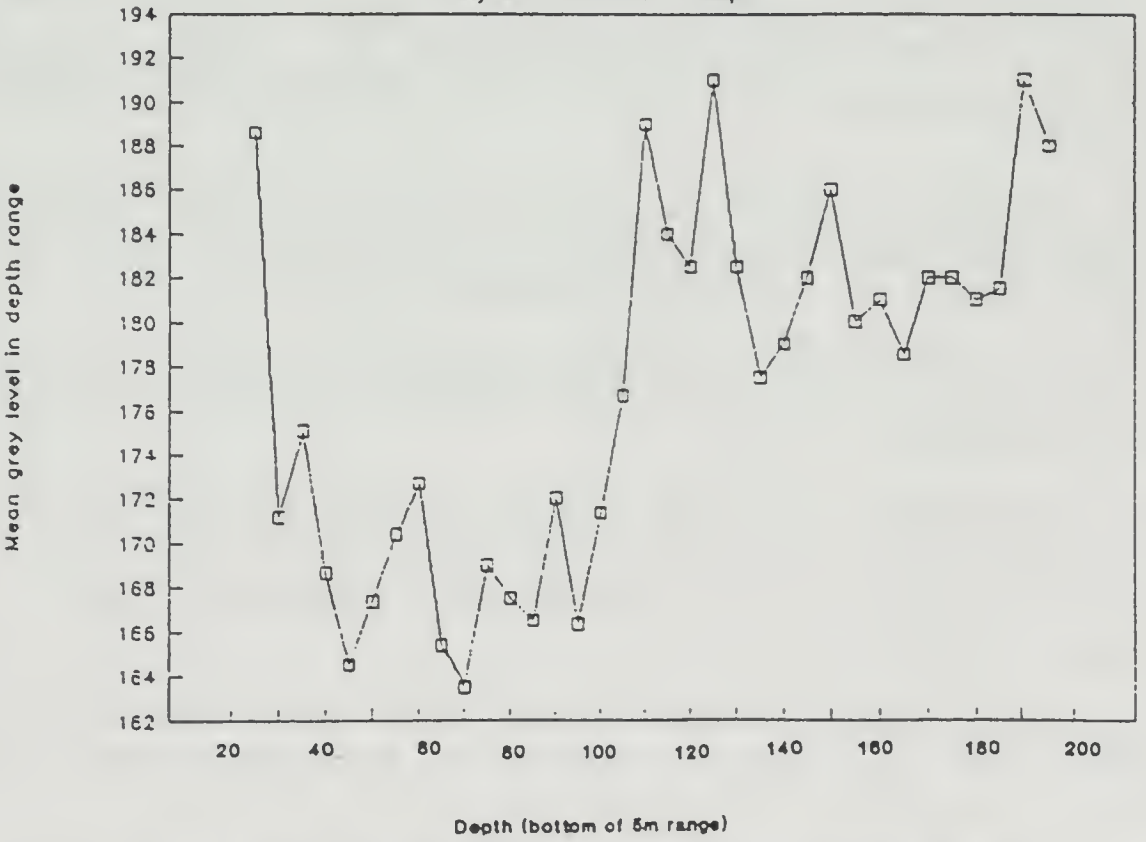
Marine Snow Camera
(23rd May 1991)

c.



Cumulative frequency shows proportions between size classes.

d.



Grey level shows clarity of water beneath 100m.

Figures 6c and 6d

Marine Snow Camera
(23rd May 1991)

2. The Loch Ness and Morar Project's 'Length Run' programme in support of the University of Lancaster's study, funded by N.E.R.C. - Plankton Community Dynamics in a Large Oligotrophic Freshwater System (Loch Ness).

3. A camera system designed to record 'aggregates' in the marine environment.

Acknowledgements

The authors would like to express their best thanks to all the collaborators of the Loch Ness and Morar Project whose diverse work has been drawn upon in the construction of this hypothesis, and in particular to Mr. William Hillier for his analysis of the Marine Snow Camera data.

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Received July 1993

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POSTSCRIPT: SURGEON OR STURGEON?

By ADRIAN J. SHINE
Loch Ness and Morar Project

It would be churlish, in view of all the recent additional information, to allow the sixtieth anniversary of the naming of the Loch Ness 'Monster' (Anon., 1933 - attributed to Mr. Alex Campbell) to pass entirely unremarked. For most people, certainly the majority of the casually interested members of the general public, the famous 'Surgeon's Photograph' of 1934 probably represents their idea of the archetypal Monster. Certainly this well-known photograph has figured in numerous publications over the past sixty-odd years, and a serious investigation and assessment of the photograph was published in the centenary (1988) volume of the *Scottish Naturalist* (LeBlond and Collins, 1988).

Acoustic Assessment of Fish Size

One consequence of the introduction of more quantifying acoustic techniques - *in situ* target strength measurement in particular - was the discovery that the great majority of pelagic fish in Loch Ness belonged to a very small size group, which were not caught prior to the trawling methods recently described (Shine, Martin and Marjoram, 1993). Therefore there was a tendency to 'scale' large sonar echoes against gill-netted individuals of 20-30 cm, which in reality represented only a small proportion of the population. This imposes a further revision upon assessment of sonar contacts which are strong in relation to the surrounding fish echoes.

Estimates of 'Monster' Population

Sheldon and Kerr (1972) first attempted estimations of theoretical 'Monster' population density based on fish biomass. They used the morphoedaphic index (total dissolved solids/mean depth), devised by Ryder (1965), to estimate the fish population. Lacking genuine Loch Ness information, however, data was used from the northern basin of Loch Lomond. For Loch Ness, a fish standing stock of between 0.55 and 2.75 kg/ha was calculated, or between 3.135 and 15.675 tonnes in total.

On-site acoustic estimates of resident pelagic fish in Loch Ness now range from 3.1 kg/ha (Shine, Martin and Marjoram, 1993) to 4.23 kg/ha (Kubecka, Duncan and Butterworth, 1993), or between 17 and 24 tonnes in total, as compared to 300

to 400 kg/ha in the upper River Thames (current acoustic estimate - Dr. J. Kubecka, pers. comm.). These estimates exceed those of Sheldon and Kerr, and may be accounted for by allochthonous organic inputs. Before hopes are raised too high, however, it should be borne in mind that predators upon this biomass should not amount to more than approximately a tenth of the gross weight. Thus we have available a total of approximately two tonnes of 'Monster', but this two tonnes may not be as great as it at first seems. For example, it would be equivalent to scarcely half the weight of a 36-ft (13 m) Whale Shark *Rhinocodon typus.* In fact, two tonnes divided into an absolute minimum viable population of, say, ten creatures, would give an individual weight of only 200 kg.

In fish terms this could be equivalent to a Sturgeon *Acipenser sturio* 2.8 m in length (Maitland and Campbell, 1992: 92). The above pelagic biomass estimates are somewhat academic since they do not include migratory Salmon *Salmo salar* or Sea Trout *Salmo trutta,* which may swim too close to the surface or too close inshore to be surveyed efficiently by acoustics. For the same reason the littoral fish habitat, which is richer than the pelagic, is not included since some of the fish, and all benthic fish e.g. Eels *Anguilla anguilla,* would be too close to the bottom to be detected. Nevertheless, it is now scarcely possible to argue a case for a population of resident 'Monster' predators.

Fish the Most Likely Candidates

After dismissing the classic Monster photographs, Shine and Martin (1988) concluded that if, among the many recorded explanations for sighting reports, large unusual creatures were indeed involved, then fish would be the most likely candidates. This was based upon the facts that Loch Ness, as a proven refuge for cold-water Ice Age relict species, was one of the last places on earth likely to be favoured by reptiles, Jurassic or otherwise. Since there are no known marine amphibia, these could not, like almost all the other vertebrate inhabitants of the loch, have made their way up the river from the sea. Finally, any mammals should long ago have advertised their presence while breathing.

The largest aquatic animal to have been recognised in Loch Ness is the Common Seal *Phoca vitulina* (Williamson, 1988), some of which occasionally enter the loch, presumably in pursuit of migrating Salmon, and could have caused some sighting reports. Salmon, the largest recorded fish in the loch, migrate inland to spawn but do not feed in fresh-water, and this habit may perhaps provide a clue to another, much larger, possible candidate which could have contributed to the Loch Ness controversy.

Resident Predators

A problem with a theoretical population of hitherto unrecorded predatory fish is that fish reproduction, whether by egg-laying or live-bearing, gives rise to relatively large numbers of small juveniles developing independent of parental care. It seems unlikely that these would have avoided capture by fishing over the years, either by towed lure or from the beach. They would also have had to evade the netting and trawling programmes described in Shine, Kubecka, Martin and Duncan (1993), let alone decades of illicit Salmon netting.

It is not inconceivable, however, that along with the Salmon and the Common Seal, Loch Ness might have played host to another visitor.

A Sturgeon?

The possibility of the afore-mentioned Sturgeon actually being responsible for the beginnings of the tradition, and for some sighting reports since then, is quite attractive. Sturgeons would not necessarily be immediately recognised as fish. They are very large, have a long upturned snout, and a dorsal fin set well back towards the tail (Figure 1a) (Gould, 1934: 136).

In 1987 a Sturgeon, eleven feet (3.35 m) long and weighing 900 lbs (408 kg) was found dead, floating in Lake Washington near Seattle, U.S.A., where stories of a 'Monster' had circulated (*Albuquerque Journal*, 7th November 1987). No-one would suggest, however, that Sturgeons would even begin to enter the reckoning, against the huge multi-humped manifestations of the 1930s ascribed by Baker (*Observer*, 26th August 1962), to boat wakes, or to many other reports. There is no one answer to the question of the Loch Ness Monster.

Sturgeons are cold-water northern hemisphere fish of very large size (up to >3.0 m) and of unusual appearance. They would be independent of the food resources, since, before entering the loch in order to spawn, they would cease feeding. Moreover, since Sturgeons are such rare visitors to British rivers, any which did succeed in passing the two weirs on the River Ness would be very unlikely to find mates. After a lonely vigil off one of the river mouths they would presumably leave again without issue, save, perhaps, for some interesting sighting reports.

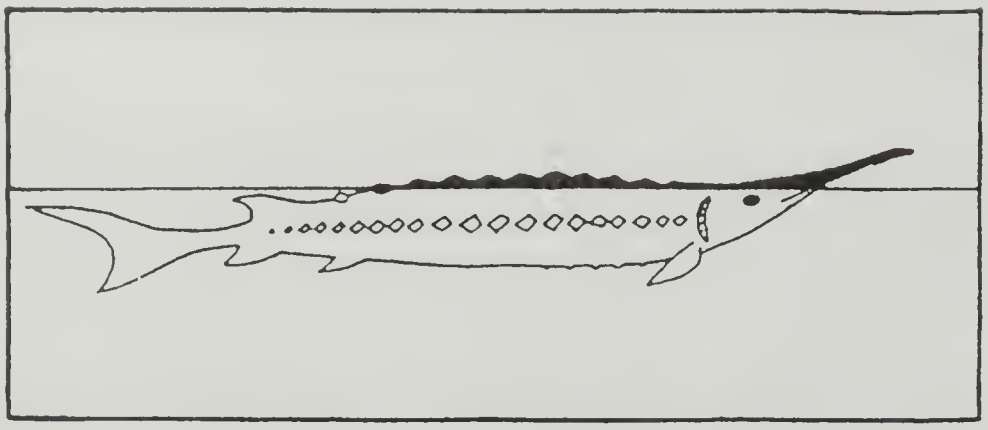


Figure 1a

Sturgeon theory proposed by Gould (1934)

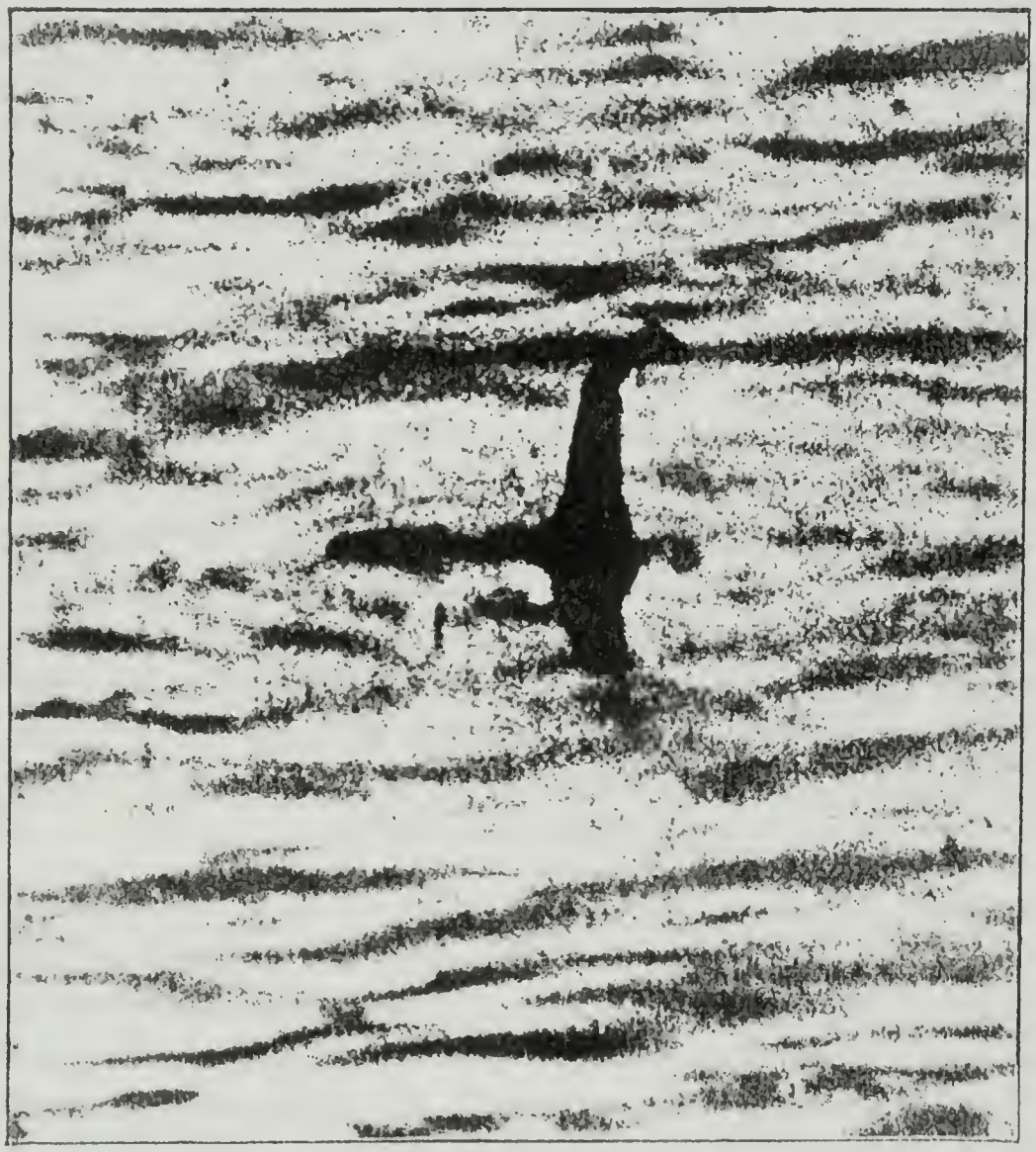


Figure 1b

The 'Surgeon's Photograph' (1934)
The long-necked stereotype.

Gould's Early Investigations

In November 1933 Lt.-Commander R.T. Gould (1934: 30) listened to the account of Mr. John McLeod, who, some 20-30 years previously had seen, at the mouth of the River Moriston beneath the lowest fall, a creature with a "head like an eel and a long tapering tail". This is how a Sturgeon might appear from above. Another witness, Miss K. MacDonald, spoke of a "crocodile"-like creature, 6-8 feet long, ascending the River Ness and heading for the Holm Mills weir, in February 1932 (Gould, 1943: 38). Rather more recently, in 1993, Mrs Marion MacDonald described to the author an experience at the Fort Augustus Abbey harbour. She saw what she first thought was a log, because of a distinctive 'scaly' bark pattern, but which then developed a wake and moved off to submerge, while she called her family. After she had sketched her impression (Figure 2) she was shown an illustration of a Sturgeon's bony plates, and considered the pattern to be reminiscent of what she had seen.

For and Against a Sturgeon

Anyone, of course, can assemble sighting reports to support a pet theory, and this one is brought forward mainly to show that, even in the absence of significant food resources, the largest freshwater fish in existence could possibly have been seen at intervals in Loch Ness. Given the large number of other causes behind sighting reports (Binns and Bell, 1983; Campbell, 1986), these intervals could be very long indeed.

There is, however, a great deal more to the Loch Ness Monster than scientific probabilities, and the greatest argument against the Sturgeon or, more importantly, against any species of fish, is the long neck reported (Figure 1b), although such reports are more rare than is generally realised. It should be borne in mind that the first report of a long neck was when the "nearest approach to a dragon or prehistoric animal" lurched its way across the hot tarmac in front of the Spicer's motor car in July 1933 (*Inverness Courier,* 4th August 1933). This unprecedented behaviour has never been reported since. Prior to this, the beast was usually considered to be an unusual fish; *Inverness Courier,* 8th October 1868 ("a huge fish"), *Northern Chronicle*, 27th August 1930 ("a fish.....or whatever it was") and *Scottish Daily Express,* 9th June 1933 ("a mystery fish").

Errors of Identification

Undoubtedly, some 'long-necked' reports originate from water birds, such as Mr. Alex. Campbell's sighting (Gould, 1934: 111), although this was subsequently revised as the archetypal plesiosaur (Witchell, 1975: 55). Some large long-necked animals have indeed been seen swimming in the loch. The author is aware of five

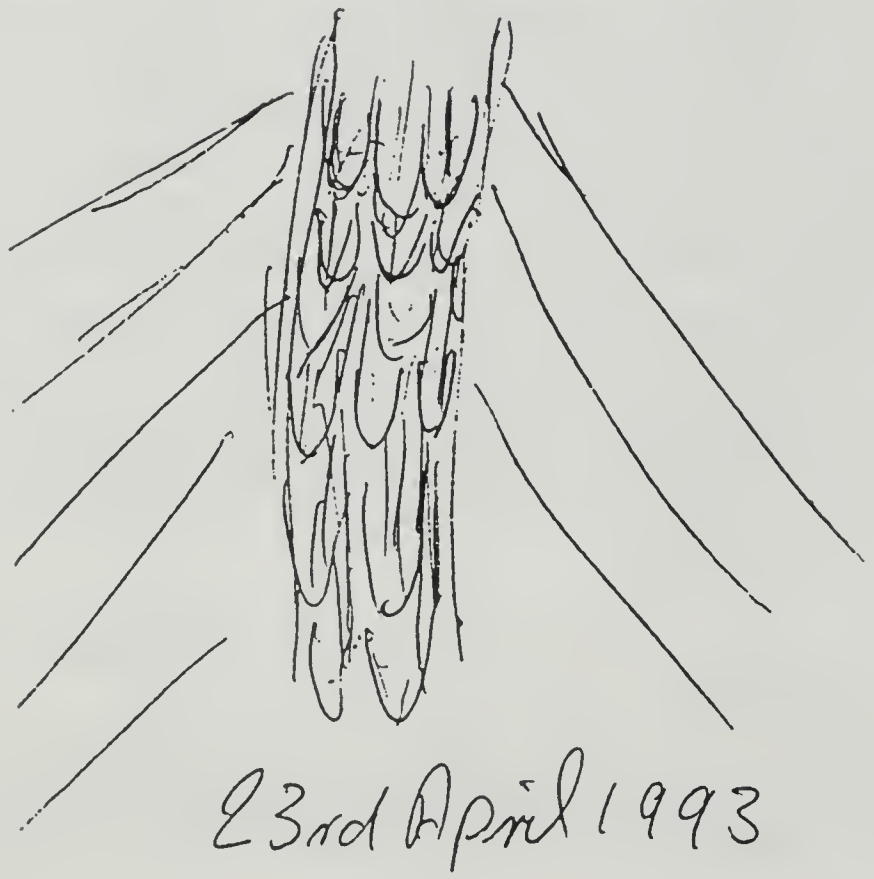


Figure 2

Sketch by Mrs Marion MacDonald of her sighting at Fort Augustus Abbey in June 1988. Approximate size was 2.0 ft wide by 5.0 ft long.

instances when such animals have subsequently been identified as swimming deer. On three occasions, photographs were taken (see Plate 1). It has been suggested by Burton (1961: 130-138) that some sightings, including some influential ones, could be due to such errors.

Experiments with Human Perception

It is now well understood that human perception consists of much more than just image, retina and memory. In contrast to 'hard' evidence, such as photographs, however, it is very difficult to assess sightings evidence because it is not usually possible to stand beside the witness. An exception to this is if an incident is contrived.

Mr. Richard Frere gives an account (Frere, 1988: 175) of standing at a busy lay-by and, through a little theatrical behaviour, drawing attention to the turbulence caused by some trawler wakes. Reactions included sightings of various humps, long dark bodies, side flippers, and a thrashing tail. A drawing produced by a child showed a plesiosaur.

On a less spectacular scale, members of the Project have also stood beside volunteer eye-witnesses, who were asked to observe an object surfacing and submerging. All were aware that we were contriving the incident, and it therefore seems possible that impressions were inspired less by pre-conceived Loch Ness Monster stereotypes than by concepts of the mechanism in the equipment. However, the results of this rather 'conservative' experiment (Figure 3) are of some interest, since 31% of the 36 observers retained impressions at some variance (Figure 3c) with the 45 cm straight-sided post they had actually seen at a range of approximately 150 m.

Given that variation exists between image and perception in such prepared observers, it seems likely that individuals, sighting unrecognised objects on Loch Ness, may well have their perceptions influenced by the well-known Monster stereotypes. It is certainly the case that the wider impression of events, as disseminated and recorded by the media, may bear little relationship to what was actually seen. For example, in a recent case Miss Edna MacInnes was widely reported as having seen a creature with a "giraffe-like" neck (*Aberdeen Press and Journal,* 25th June 1993). When interviewed later she denied this, and stated that she had used the word "giraffe" in the context of conveying the sense of movement which the object made. Her drawing appears in Figure 4.

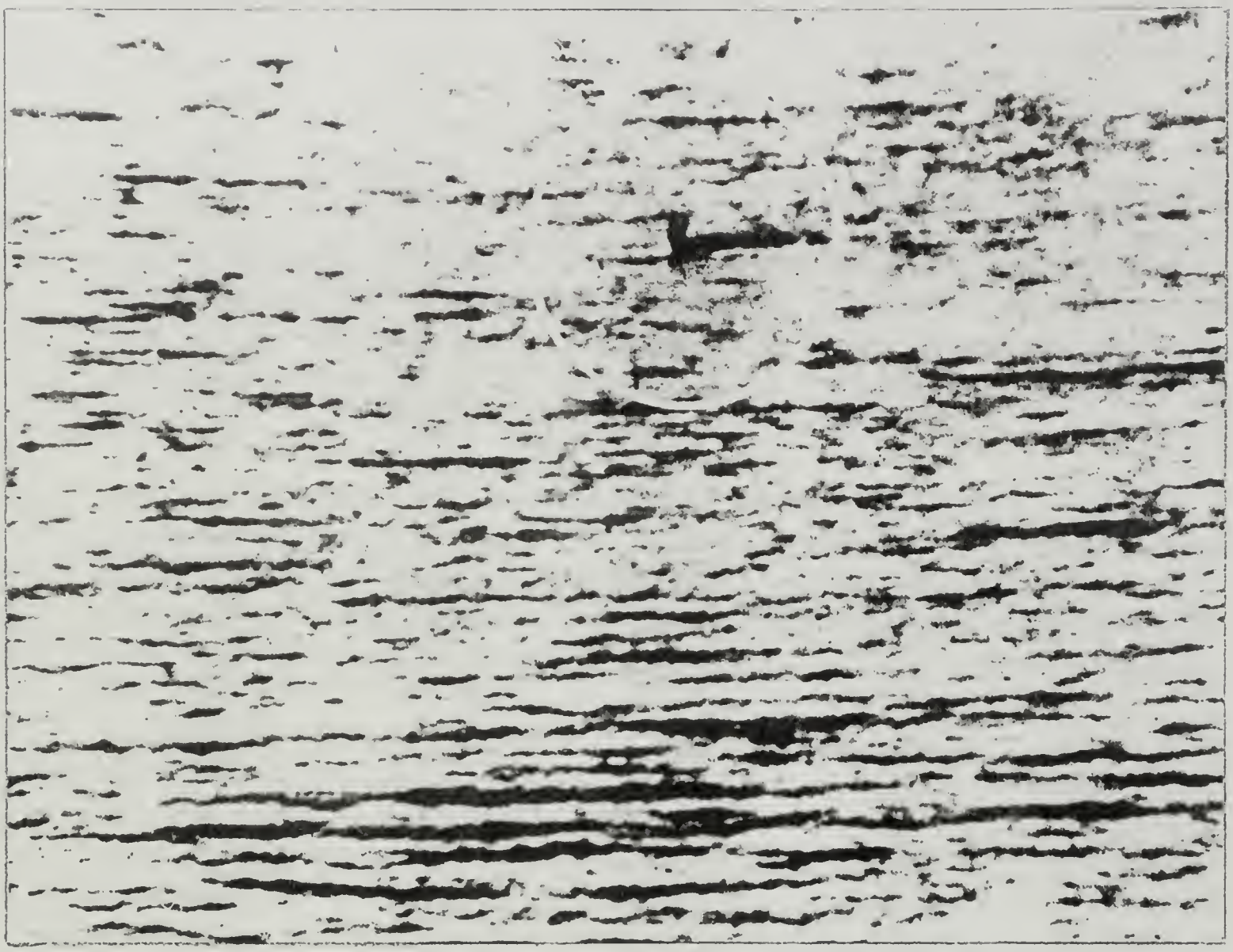
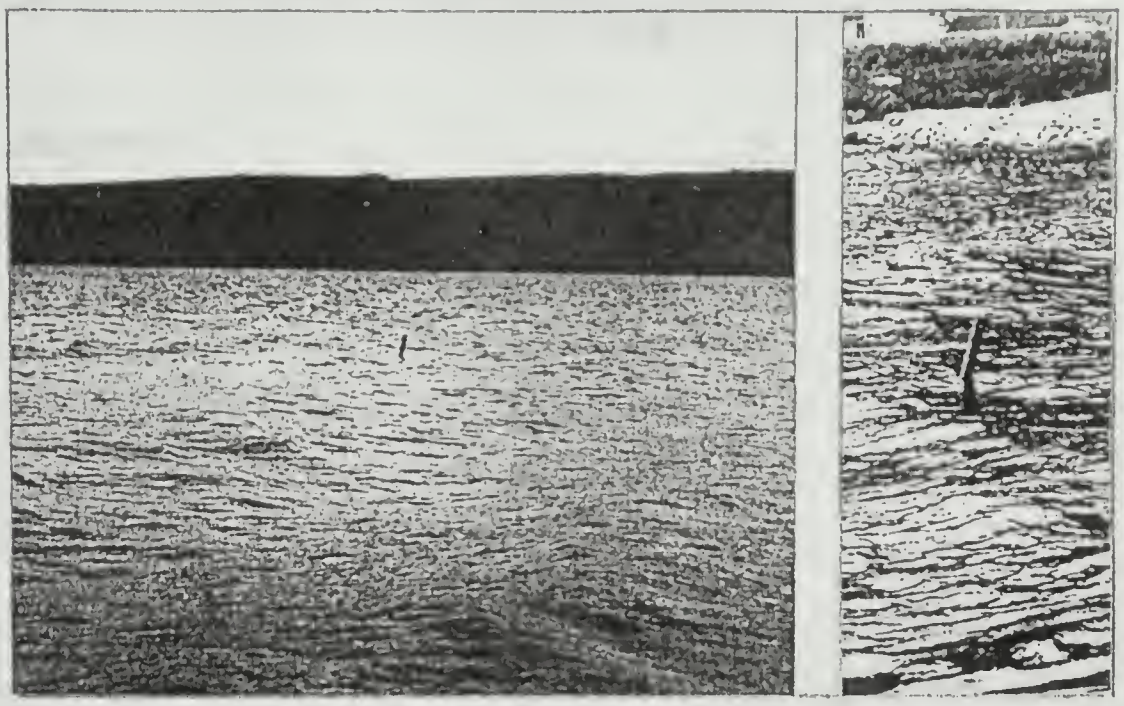


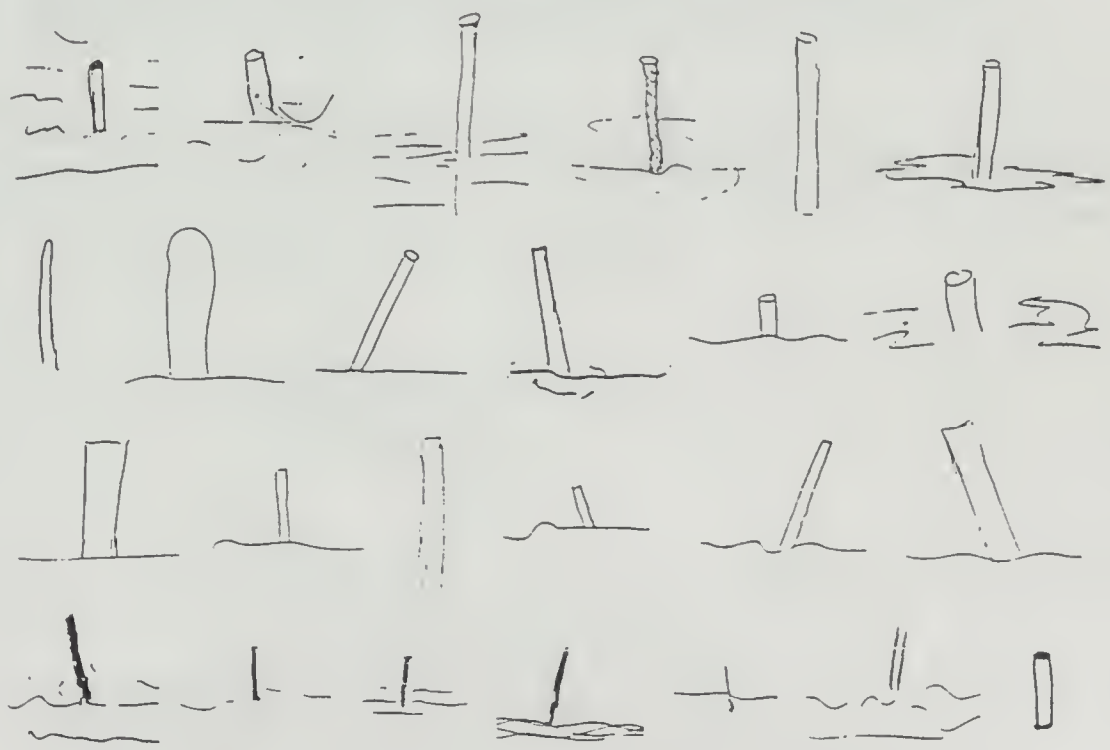
Plate 1

Deer swimming in Loch Ness

a. A 45cm rectangular post 150m from the observer.



b. Most people retain a fairly accurate impression of the incident.



c. 31% however, apply a rationalisation to what is seen.

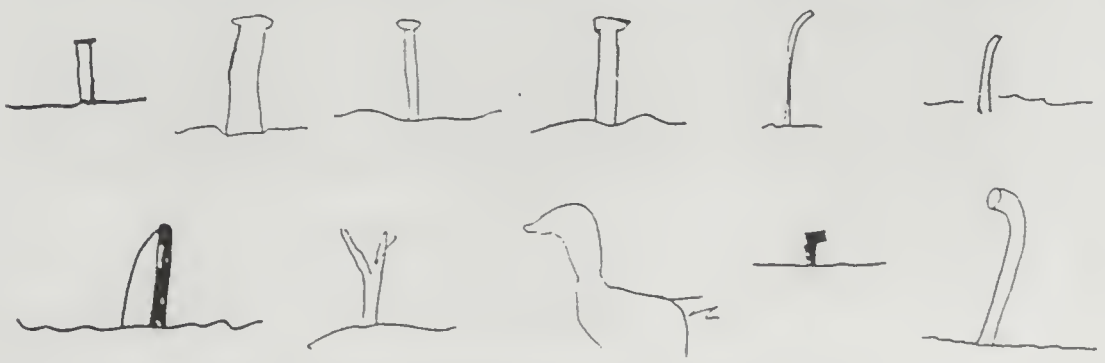


Figure 3: Perception Tests

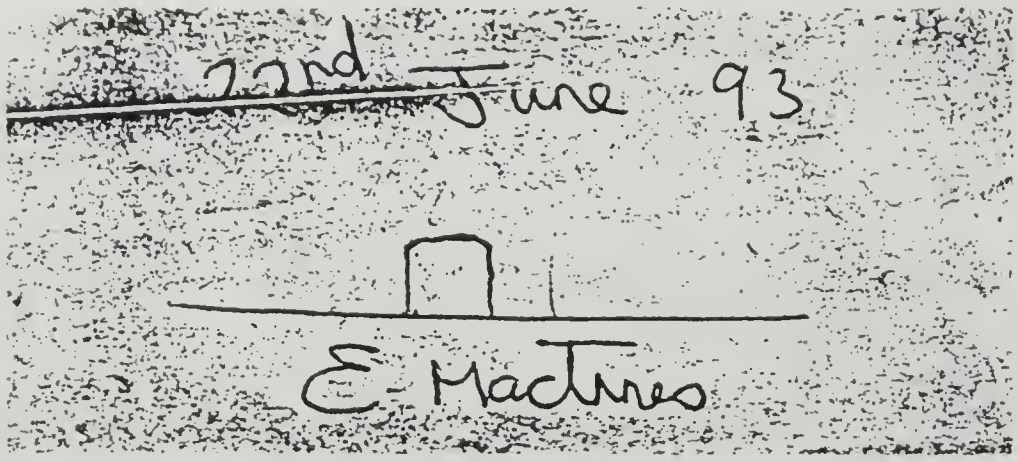


Figure 4

Sketch by Miss Edna MacInnes of her sighting
(22nd June 1993)

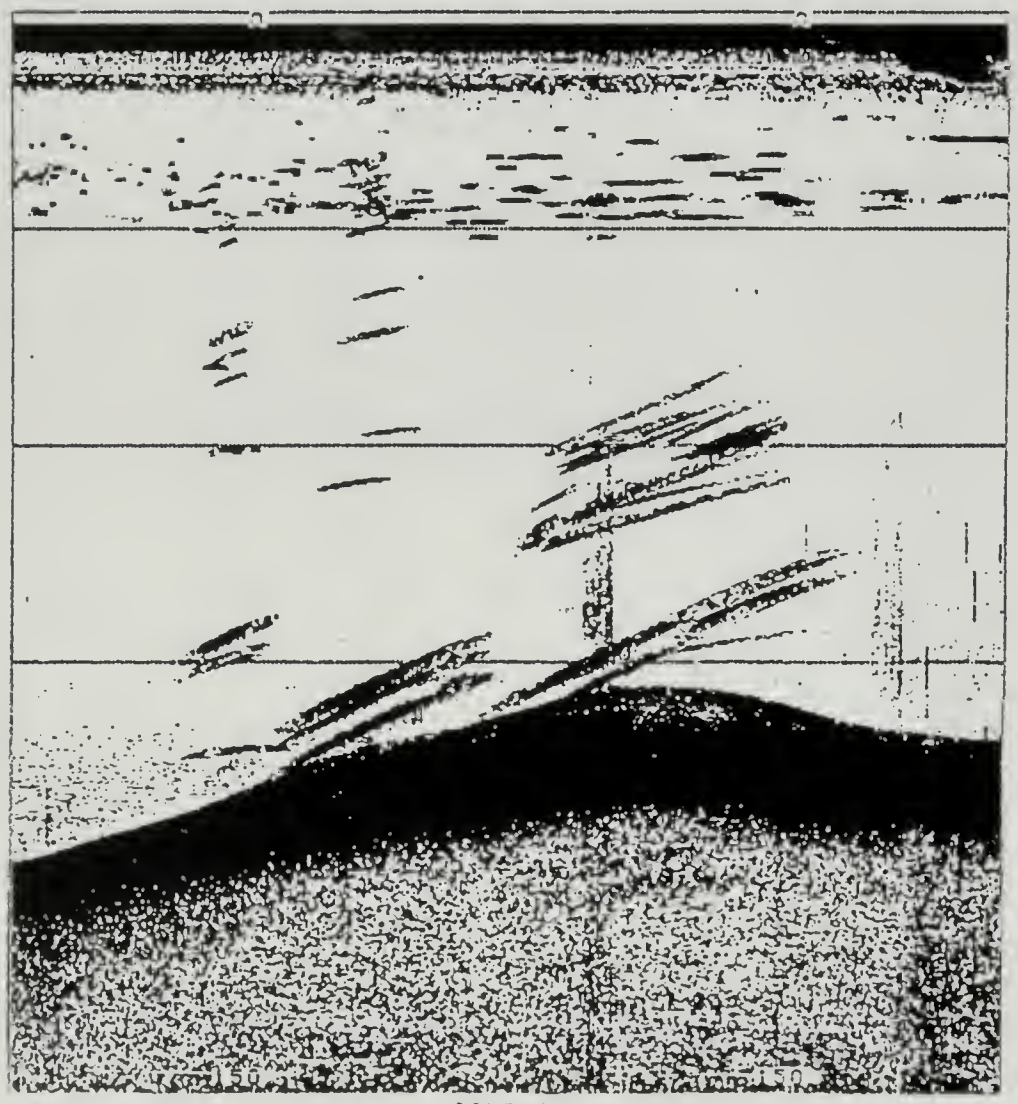


Figure 5

Gas rising from the sediments 97 m deep
off Fort Augustus.

Some Conclusions

Burton (1961: 91) suggested that gas such as methane could bring decaying vegetation, perhaps including branches resembling necks, to the surface. In the main, the Project's work has shown little gas production in deep Loch Ness sediments. There are two exceptional areas, however; one is a small area in Urquhart Bay, and there is a larger one off Fort Augustus, where great quantities of organic material accumulate and emit gas continuously during the summer. On one occasion (Figure 5) gas was detected from a source as deep as 97 m, which remained active for two weeks. It seems that vegetable debris, including branches, could break the surface in this particular 'Monster spot'.

The morals of this story are two-fold. Firstly, large creatures may plausibly be witnessed in Loch Ness, whether or not science discovers sufficient red-herrings with which to feed them. On the other hand, the types of creatures suggested by science should not be over-ruled simply because they do not fit all witness perceptions.

Those who find the author's attempts to modify the status of the very long-necked sightings unsatisfactory, may take comfort from the 'Surgeon's Photograph', standing guard over popular expectations for some sixty years, and confounding any science to take itself too seriously.

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Received July 1993

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1871

The Scottish Naturalist
1872-1891

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1892-1911

The Scottish Naturalist
1912-1939, 1948-1957, 1961-1964

The Western Naturalist
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